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BASELINE TESTS OF THE DAIHATSU EH-S40 ELECTRIC DELIVERY VAN.(U)
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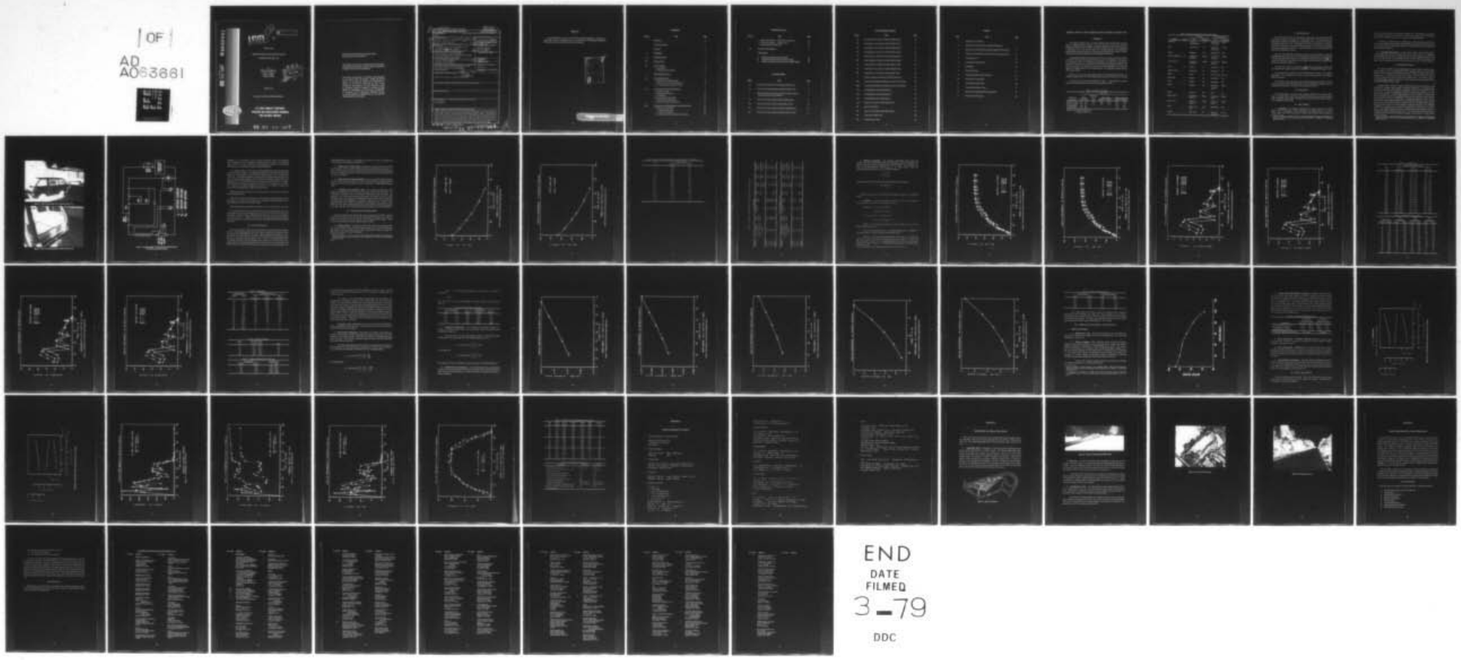

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Report 2256

BASELINE TESTS OF THE DAIHATSU EH-S40

ELECTRIC DELIVERY VAN

by
Edward J. Dowgiallo, Jr.
Cornelius E. Bailey, Jr.
Ivan R. Snellings
William H. Blake

August 1978

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U.S. ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT COMMAND
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER 2256	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 BASELINE TESTS OF THE DAIHATSU EH-S40 ELECTRIC DELIVERY VAN .		5. TYPE OF REPORT & PERIOD COVERED 9 Final Technical ~~Memorandum~~
		6. PERFORMING ORG. REPORT NUMBER 19 CONS/0421-2
7. AUTHOR(s) 10 Edward J. Dowgiallo, Jr., Cornelius E. Bailey, Jr., Ivan R. Snellings[redacted] William H. Blake		8. CONTRACT OR GRANT NUMBER(s) Interagency Agreement 15 EC-77-A-31-1042
9. PERFORMING ORGANIZATION NAME AND ADDRESS Electro Chem Div, Elec Pwr Lab, DRDME-EC U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Mobility Equipment Research and Development Command; ATTN: DRDME-EC Fort Belvoir, Virginia 22060		12. REPORT DATE 11 Aug[redacted]78
		13. NUMBER OF PAGES 55
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Department of Energy; Elec & Hybrid Highway Vehicle Systems Program, Division of Transportation Energy Conservation		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

12 62p.

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electric Vehicle

Traction Battery

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Daihatsu EH-S40 Van, an electric quarter-ton delivery truck, was tested at the U.S. Army Aberdeen Proving Ground test facilities in Aberdeen, Maryland, as part of a Department of Energy (DOE) project to characterize the state-of-the-art of electric vehicles. The EH-S40 Van performance test results are presented in this report. The EH-S40 Van is manufactured in Osaka, Japan, by Daihatsu Motor Co., Ltd. The van is powered by eight 12-volt batteries that are connected to the motor through an arrangement of contactors operated from a foot pedal. The motor is a compound type with a transistor shunt field control. The motor is connected via a clutch to a four-speed manual transmission. No regenerative braking was provided.

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PREFACE

Acknowledgement is made of the many beneficial suggestions, computer programming, and data tabulations made by the Scientific and Engineering Application Staff Group members, David Scott and Arthur Nickless.

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BASELINE TESTS OF THE DAIHATSU EH-S40 ELECTRIC DELIVERY VAN

I. SUMMARY

The Daihatsu EH-S40 Van, an electric delivery truck manufactured in Osaka, Japan by Daihatsu Motor Company, Ltd, was tested at the U.S. Army Aberdeen Proving Ground (APG) test facilities in Aberdeen, Maryland, between 30 August and 9 September 1977. The tests are part of an Energy Research and Development Administration (ERDA) project to characterize the state-of-the-art of electric vehicles. This report presents the performance on the Daihatsu EH-S40 Van.

The Daihatsu EH-S40 Van Model S40-817192 is a quarter-ton electric delivery truck with a reinforced steel body, powered by eight 12-volt batteries. The batteries are connected to the motor through an arrangement of contactors operated from a foot pedal. The motor is a compound type with a transistor shunt field control. The motor is connected via a clutch to a four-speed manual transmission. The contactors change the voltage applied to the 14-kilowatt motor. No regenerative braking was provided on this vehicle.

All tests were run at the gross vehicle weight of 1225 kilograms (2700 lbm). The EH-S40 accelerated from 0 to 48.3 kilometers per hour (0 to 30 mi/h) in 21 seconds.

The results of the tests are summarized in Table 1. The parameters, symbols, units, and unit abbreviations used in this report are given in Table 2.

Table 1. Summary of Test Results

Test Speed or Driving Cycle	Range (km)	Range (mi)	Road Load Power (kW)	Road Energy (MJ/km)	Road Energy (kWh/mi)	Energy Consumption (MJ/km)	Energy Consumption (kWh/mi)
40 km/h (25 mi/h)	60.5	37.6	3.92	0.36	0.16	0.62	0.28
56 km/h (35 mi/h)	45.5	28.3	6.85	0.43	0.19	0.82	0.37
J227a Schedule B	37.8	23.5	–	–	–	1.14	0.51
J227a Schedule C	32.8	20.4	–	–	–	1.14	0.51

Acceleration: 0 to 32 km/h (20 mi/h) in 12 s.
0 to 48 km/h (30 mi/h) in 21 s.

Table 2. Parameters, Symbols, Units, and Unit Abbreviations

Parameter	Symbol	SI Units		U.S. Customary Units	
		Unit	Abbreviation	Unit	Abbreviation
Acceleration	a	meter per second squared	m/s^2	mile per hour per second	mi/h/s
Area		square meter	m^2	square foot; square inch	ft^2; $in.^2$
Energy	–	megajoule	MJ	kilowatt hour	kWh
Energy Consumption	E	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mi
Energy Economy	–	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mi
Force	F	newton	N	pound force	lbf
Integrated current	–	ampere hour	Ah	ampere hour	Ah
Length		meter	m	inch; foot; mile	in.; ft; mi
Mass; weight	w	kilogram	kg	pound mass	lbm
Power	P	kilowatt	kW	horsepower	hp
Pressure	–	kilopascal	kPa	pound force per square inch	lbf/in^2
Range	–	kilometer	km	mile	mi
Specific energy	–	megajoule per kilogram	MJ/kg	watt hour per pound	Wh/lbm
Specific power	–	kilowatt per kilogram	kW/kg	kilowatt per pound	kW/lbm
Speed	V	kilometer per hour	km/h	mile per hour	mi/h
Volume		cubic meter	m^3	cubic inch; cubic foot	$in.^3$; ft^3

II. INTRODUCTION

The vehicle tests and the data presented in this report are in support of Public Law 94-413 enacted by Congress on 17 September 1976. The Law requires the Department of Energy to develop data characterizing the state-of-the-art of electric and hybrid vehicles. The data so developed are to serve as a baseline (1) to compare improvements in electric and hybrid vehicle technologies, (2) to assist in establishing performance standards for electric and hybrid vehicles, and (3) to help guide future research and development activities.

The US Army Mobility Equipment Research and Development Command (MERADCOM) under the direction of the Electric and Hybrid Research, Development, and Demonstration Office, Division of Transportation Energy Conservation, DOE, has conducted track tests of electric vehicles to measure their performance characteristics and vehicle component efficiencies.

The tests were conducted according to DOE Electric and Hybrid Vehicle Test and Evaluation Procedures, described in Appendix E of MERADCOM Report 2244.[1]

The assistance and cooperation of the Daihatsu Motor Company, Ltd. are greatly appreciated. The Department of Energy provided funding support and guidance during this project.

US customary units were used in the collection and reduction of data. The units were converted to the International System of Units (Systeme International, SI) for presentation in this report. US customary units are also presented.

III. OBJECTIVES

The characteristics of interest for the Daihatsu EH-S40 Van are vehicle speed, range at constant speed, range over stop-and-go driving schedules, maximum acceleration, gradeability, road energy consumption, road power, indicated energy consumption, and battery characteristics.

IV. TEST VEHICLE

1. **Description.** The Daihatsu EH-S40 Van, an electric delivery truck, model S40-817192, is a quarter-ton vehicle manufactured by Daihatsu Motor Co., Ltd., in Osaka, Japan. The vehicle is powered by eight 12-volt batteries that are located on

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[1] Edward J. Dowgiallo, Jr.; Cornelius E. Bailey, Jr.; Ivan R. Snellings; William H. Blake; and Donald Sherwood; "Baseline Tests of the EVA Metro Electric Passenger Vehicle (DOE Report No. CONS/0421-1)." MERADCOM Report 2244 (Jul 78).

the floor of the cargo area in two slide-out plastic tubs. The batteries are connected to the motor through an arrangement of contactors operated from a foot pedal. The motor is connected via a clutch to a four-speed manual transmission.

The battery, a controller, and a 14-kilowatt d.c. shunt motor are connected in series. The controller circuit applies battery voltage to the motor armature by means of a contactor and a circuit which controls the motor field by means of a transistor chopper control (Figure 1).

2. **Operating Characteristics.** A Key switch is used to close the main switch; a foot pedal selects the three voltage levels to the motor. Step one is through a current-limiting resistor; step two is through half of the current-limiting resistor; and step three bypasses the current-limiting resistor to allow maximum voltage to the motor. Field weakening is used to keep the armature current constant (Figure 2).

V. INSTRUMENTATION

The Daihatsu EH-S40 Van was instrumented to measure vehicle speed and range, battery voltage, current, "instantaneous" power, averaged power, and motor voltage (motor current was assumed approximately equal to battery current). The battery charger input a.c. kilowatt-hours and output amperes were also measured. Battery electrolyte temperatures were measured with thermometers. A brief description of the instrumentation system is given below. Details on the recorder are given in Appendix B of MERADCOM Report 2244.[2]

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Instrumentation consisted of signal conditioning circuits and a magnetic tape recorder for recording analog signals of electrical parameters. The magnetic tape recorder was operated in the frequency modulation mode at 1.875 inches (4.763 cm) per second. The signal conditioning circuitry to the recorder consisted of a main battery voltage divider, a shunt-voltage amplifier for current monitor, an analog multiplier, and averager circuits for averaging power and current, since the recorder response was less than 0.3 db down at 500 Hertz. A voltage proportional to power was produced by the instantaneous multiplication of voltages proportional to battery voltage and current. Current and power were recorded both raw and electronically averaged. The raw values include the rapid switching transients associated with solid-state controller. An estimation of the overall d.c. measurement error is less than ±1.8% for power. This includes digitization from the field-recorded analog magnetic tape to a computer-compatible digitized magnetic tape. The measurement error of the various conditioning circuits can be broken down as follows: Current shunt (± 0.25%); current

[2] Edward J. Dowgiallo, Jr.; Cornelius E. Bailey, Jr.; Ivan R. Snellings; William H. Blake; and Donald Sherwood; "Baseline Tests of the EVA Metro Electric Passenger Vehicle (DOE Report No. CONS/0421-1)." MERADCOM Report 2244 (Jul 78).

Figure 1A. Partial Front and Side View of Daihatsu EH-S40 Van.

Figure 1B. Rear View Showing Batteries in Slide-Out Plastic Tubs.

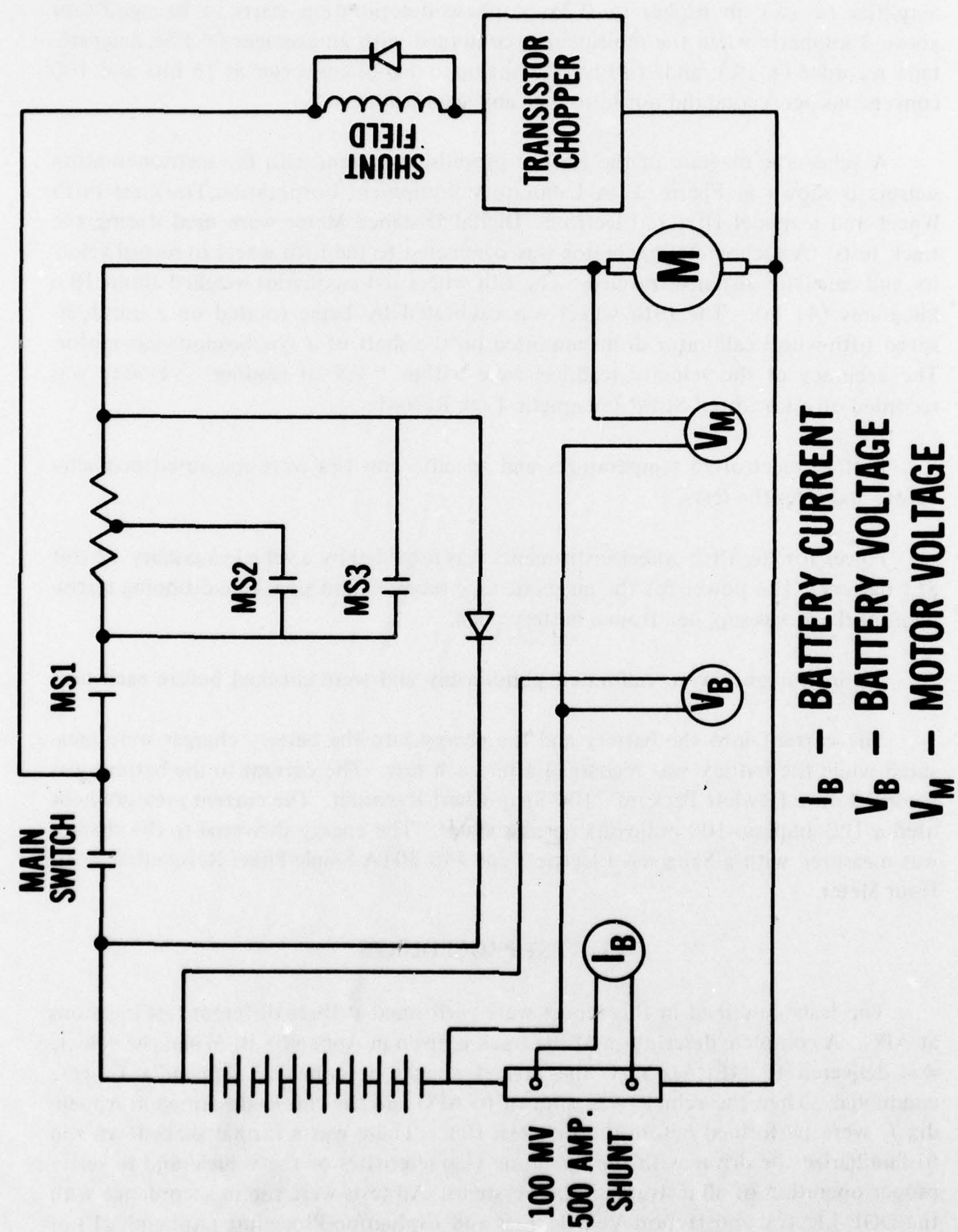

Figure 2. Schematic Diagram of Vehicle Electric Propulsion System Showing Instrumentation Monitors

amplifier (± 1%); multiplier (± 0.25%); phase deterioration starts to be significant above 3 kilohertz when the multiplier is combined with an averager (± 1%); magnetic tape recorder (± 1%); and, finally, the analog-to-digital converter at 16 bits and 100 conversions per second did not introduce any significant error.

A schematic diagram of the electric propulsion system with the instrumentation sensors is shown in Figure 2. A Laboratory Equipment Corporation, Tracktest Fifth Wheel and a model DD1.1, Electronic Digital Distance Meter were used during the track tests. A tachometer generator was connected to the fifth wheel to record velocity and calculate distance traveled. The fith wheel and auxiliaries weighed about 18.6 kilograms (41 lb). The fifth wheel was calibrated by being rotated on a constant-speed fifth-wheel calibrator drum mounted on the shaft of a synchronous a.c. motor. The accuracy of the velocity readings were within ± ½% of reading. Velocity was recorded on a Lockheed Store 7 Magnetic Tape Recorder.

Battery electrolyte temperatures and specific gravities were measured manually before and after the tests.

Power for the fifth wheel instruments was provided by a vehicle auxiliary 12-volt SLI battery. The power for the magnetic tape recorder and signal conditioning instrument package was supplied from a battery pack.

All instruments were calibrated periodically and were checked before each test.

The current into the battery and the energy into the battery charger were measured while the battery was recharged after each test. The current to the battery was recorded on a Hewlett Packard 7100 Strip Chart Recorder. The current measurement used a 100 amperes-100 millivolts current shunt. The energy delivered to the charger was measured with a Sangamo Electric Type J4S 30TA Single-Phase Reisdential Watt-Hour Meter.

VI. TEST PROCEDURES

The tests described in this report were performed at three different test locations at APG. A complete description of the track is given in Appendix B. When the vehicle was delivered to MERADCOM, the pretest checks described in Appendix C were conducted. Then the vehicle was shipped to APG and the checks described in Appendix C were performed before the first test run. There was a formal shakedown run to familiarize the driver with the operating characteristics of the vehicle and to verify proper operation of all instrumentation systems. All tests were run in accordance with the DOE Electric and Hybrid Vehicle Test and Evaluation Procedure (Appendix E) of

MERADCOM Report 2244.[3] No braking tests, tractive force tests, or handling tests were performed on the Daihatsu EH-S40 Van.

1. **Range Tests at Constant Speed.** Range tests at constant speed were carried out at 40 km/h (25 mi/h) and 56.3 km/h (35 mi/h); speeds held constant within ± 1.6 km/h (1 mi/h) and the test was terminated when the vehicle could no longer maintain 95% of the designated test speed. The range tests were run two times at 40 km/h and one time at 56.3 km/h.

2. **Range Tests Under Driving Schedules.** The 32.2 km/h (20 mi/h), schedule B, and 48.3 km/h (30 mi/h), schedule C were run with this vehicle. Complete descriptions of the cycle test procedures are given in Appendix E of MERADCOM Report 2244.[4]

3. **Acceleration and Coast-Down Tests.** The maximum acceleration of the vehicle was measured on a level road with the battery at three states of charge. The acceleration coast-down tests were performed continuously until the battery was discharged. The vehicle was operated in this manner two times for each full state of charge. Data were recorded on an analog magnetic tape recorder and, later, digitized and calculations were performed on a computer. These tests were conducted on the Dynamometer Course at APG (see Appendix B for description of the course). Coast-down data were taken following each maximum acceleration run with the transmission in neutral. The speed versus time plots are shown in Figures 3A and 3B and Table 3.

VII. TEST RESULTS AND DISCUSSION

The data collected from all the range tests are summarized in Table 4. Shown in the table are the test data, type of test, environmental conditions, the range test results, the amp-hours out of the battery, and the energy into the charger. These data are used to determine vehicle range and energy economy.

1. **Maximum Speed.** The maximum speed of the vehicle was measured during the acceleration tests. The measured maximum speed was 67 km/h (41.9 mi/h) for this vehicle. Note this differs from the top speed used in the range test which was limited to 35 mi/h at the request of Daihatsu.

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3 Edward J. Dowgiallo, Jr.; Cornelius E. Bailey, Jr.; Ivan R. Snellings; William H. Blake; and Donald Sherwood; "Baseline Tests of the EVA Metro Electric Passenger Vehicle (DOE Report No. CONS/0421-1)." MERADCOM Report 2244 (Jul 78).

4 Ibid.

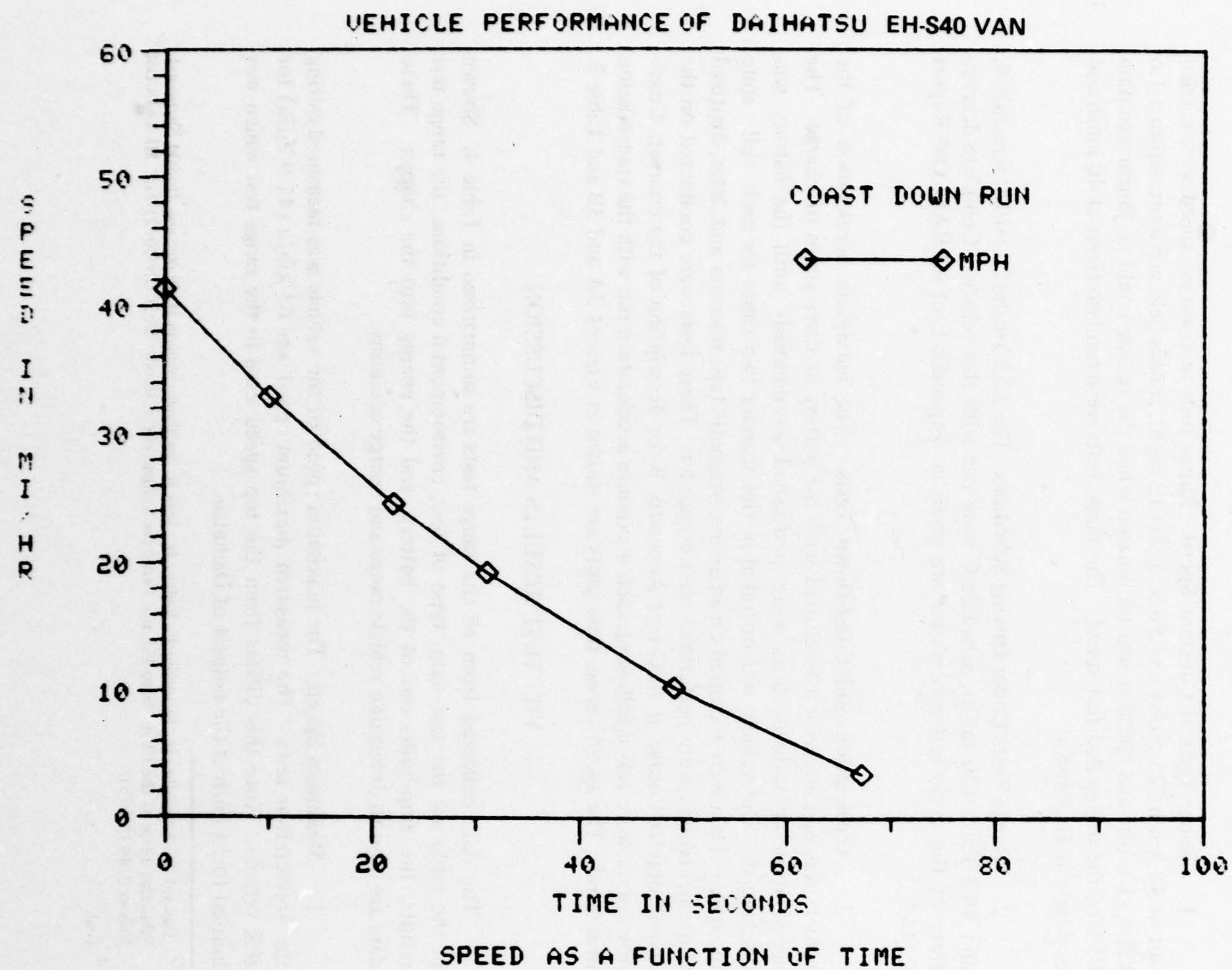

Figure 3A. Speed Versus Time During Coasting (English Units).

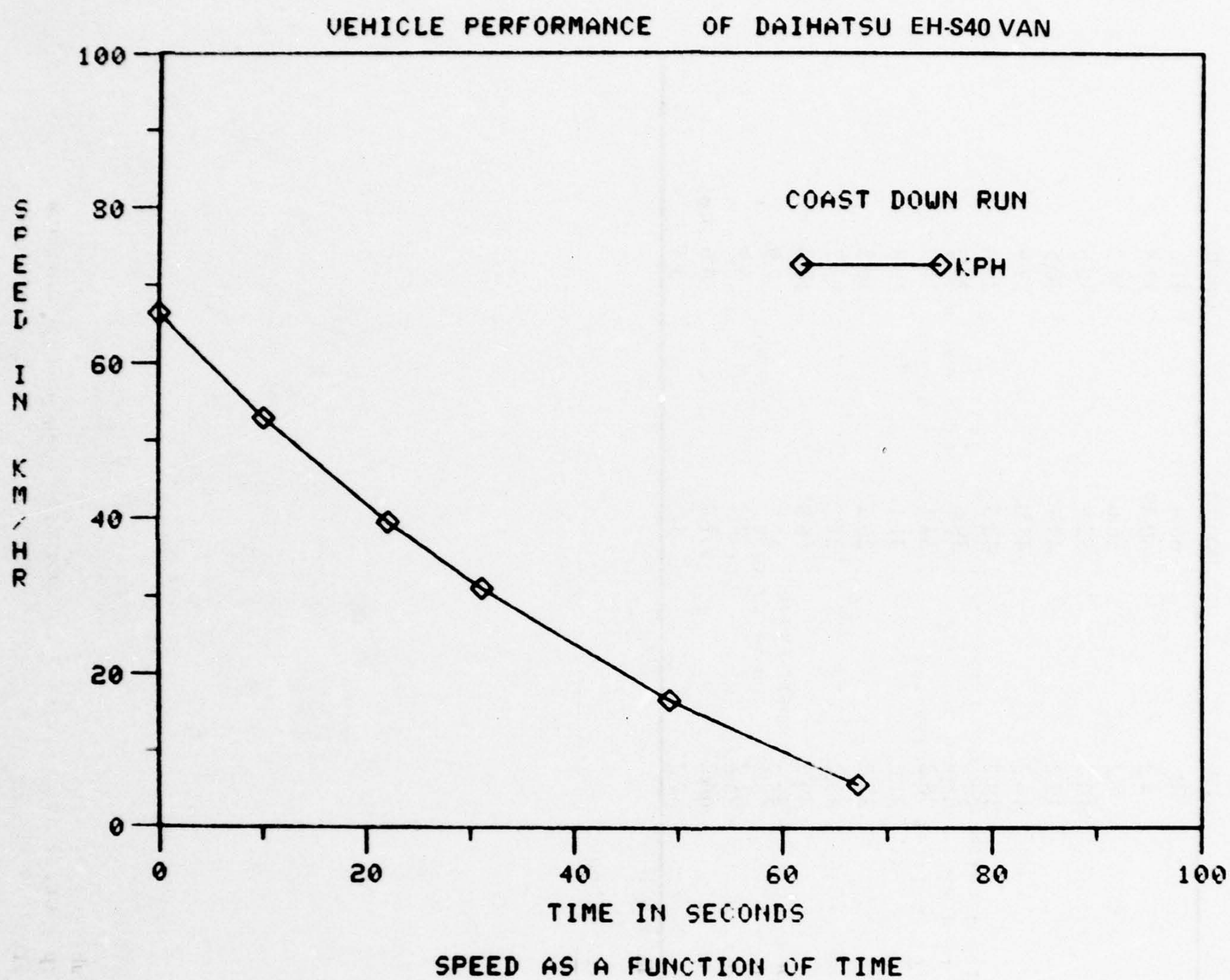

Figure 3B. Speed Versus Time During Coasting (Metric Units).

Table 3. Speed Versus Time During Coasting for Daihatsu EH-S40 Van

Time	Vehicle Speed	
(s)	(km/h)	(mi/h)
0	66.4	41.3
4.2	60.39	37.5
7.2	56.6	35.2
10.2	52.9	32.9
13.2	49.1	30.5
16.2	45.0	27.9
19.2	42.5	26.4
22.2	39.6	24.6
28.2	34.1	21.2
31.2	31.1	19.3
37.2	26.2	16.3
43.2	21.2	13.2
49.2	16.8	10.4
55.2	12.7	7.9
61.2	9.2	5.7
64.2	7.4	4.6
67.2	5.7	3.5

Table 4. Summary of Test Results in SI Units and US Customary Units

(a) SI Units

Test Date	Test Condition (Constant Speed) (km/h); or Driving Schedule	Wind Velocity (km/h)	Temperature (°C)	Range (km)	Number of Cycles	Ampere-Hours from Battery (Ah)	Energy into Charger (MJ)	Indicated Energy Consumption (MJ/km)
8-31-77	40	calm	28	60.8			37.4	0.63
9-1-77	56	3.2	26	45.5		71.3	37.4	0.82
9-2-77	40	calm	27	60.0		76.5	37.4	0.62
9-7-77	B	12.8	20	37.8	106	95.4	43.2	1.14
9-8-77	C	6.4	20	32.8	58	70.5	37.4	1.14

(b) US Customary Units

Test Date	Test Condition (Constant Speed) (km/h); or Driving Schedule	Wind Velocity (mi/h)	Temperature (°F)	Range (mi)	Number of Cycles	Ampere-Hours from Battery (Ah)	Energy into Charger (kWh)	Indicated Energy Consumption (kWh/mi)
8-31-77	25	calm	82	37.8			10.4	0.28
9-1-77	35	2	79	28.3		71.3	10.4	0.37
9-2-77	25	calm	81			76.5	10.4	0.28
9-7-77	B	8	68	23.5	106	95.4	12.0	0.51
9-8-77	C	4	68	20.4	58	70.5	10.4	0.51

2. **Maximum Acceleration.** The maximum acceleration of the vehicle was measured with the batteries fully charged, 40% discharged, and 80% discharged. The results of the tests are shown in Figures 4A and 4B and Table 5. The average acceleration, $\bar{a}_n$, was calculated for the time period t_{n-1} to t_n (SAE J227a)[5] where the vehicle speed increased from V_{n-1} to V_n, from the equation:

$$\bar{a}_n = \frac{V_n - V_{n-1}}{t_n - t_{n-1}}$$

and the average speed of the vehicle, $\bar{V}$, was calculated from the equation:

$$\bar{V} = \frac{V_n + V_{n-1}}{2}$$

Average acceleration as a function of speed is shown in Figures 5A and 5B and Table 6.

3. **Gradeability.** The maximum vehicle speed on a specific grade is determined from maximum acceleration tests by using the equations:

Gradeability, G, at a speed $\bar{V}$, in km/h:

$$G = 100 \tan (\sin^{-1} 0.1026 \bar{a}_n) \%$$

or in English units, at a speed $\bar{V}$ in mi/h:

$$G = 100 \tan (\sin^{-1} 0.0455 \bar{a}_n) \%$$

where: $\bar{a}_n$ = acceleration in meters per second squared (m/s^2) or in miles per hour per second (mi/h/s).

The resulting maximum grade the Daihatsu EH-S40 Van can negotiate as a function of speed is shown in Figures 6A and 6B and Table 7.

The vehicle was tested for longitudinal slope performance in lieu of drawbar-pull tests. The results of the slope tests, conducted at a test weight of 1225 kg (2700 lb), are shown in Table 8. The computed drawbar-pull in first gear, based on slope performance is given in Table 9. It is estimated that the Daihatsu Van has the power

[5] Society of Automotive Engineers, "Electric Vehicle Test Procedure." SEA J227a (Feb 76).

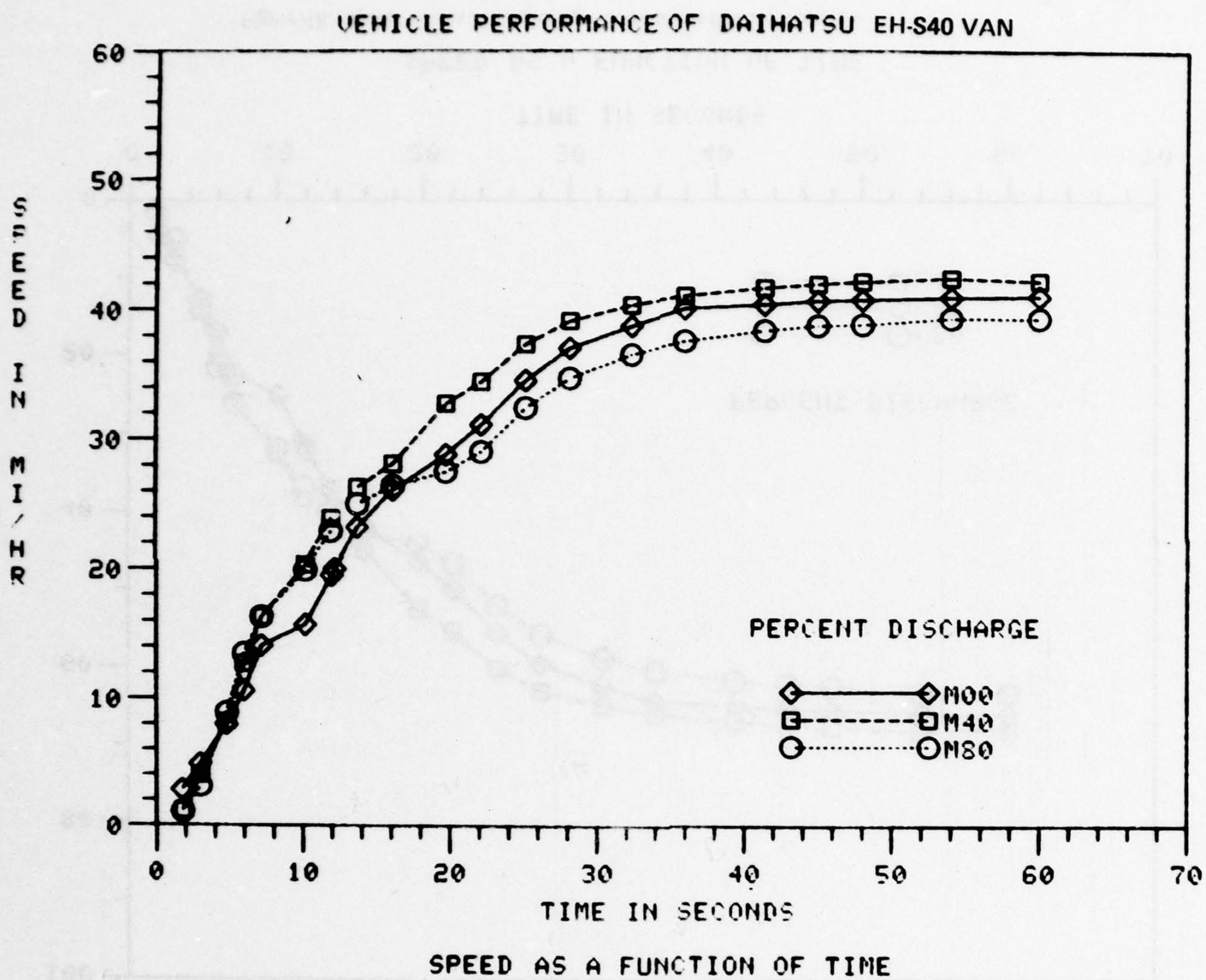

Figure 4A. Speed Versus Time During Acceleration (English Units).

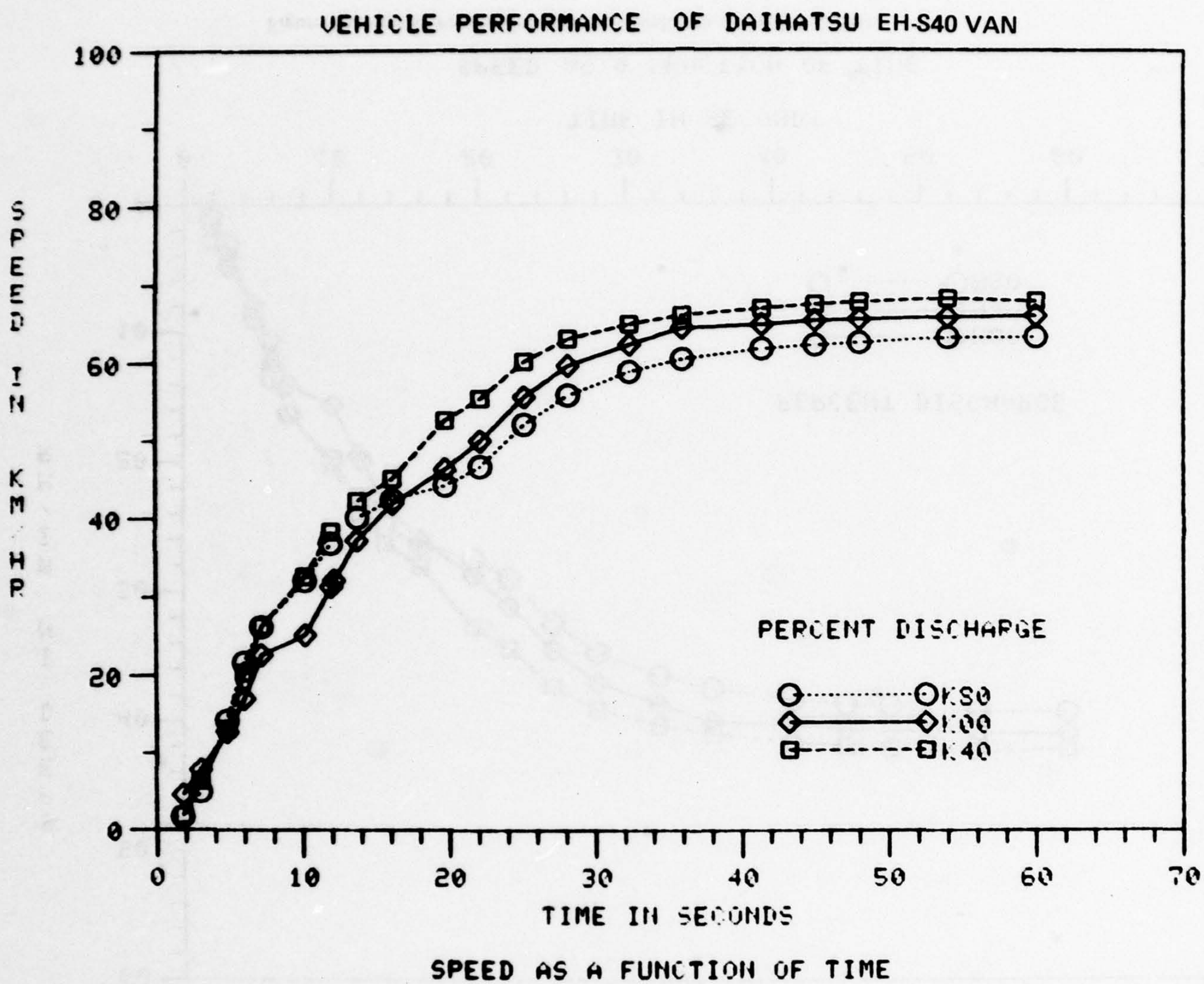

Figure 4B. Speed Versus Time During Acceleration (Metric Units).

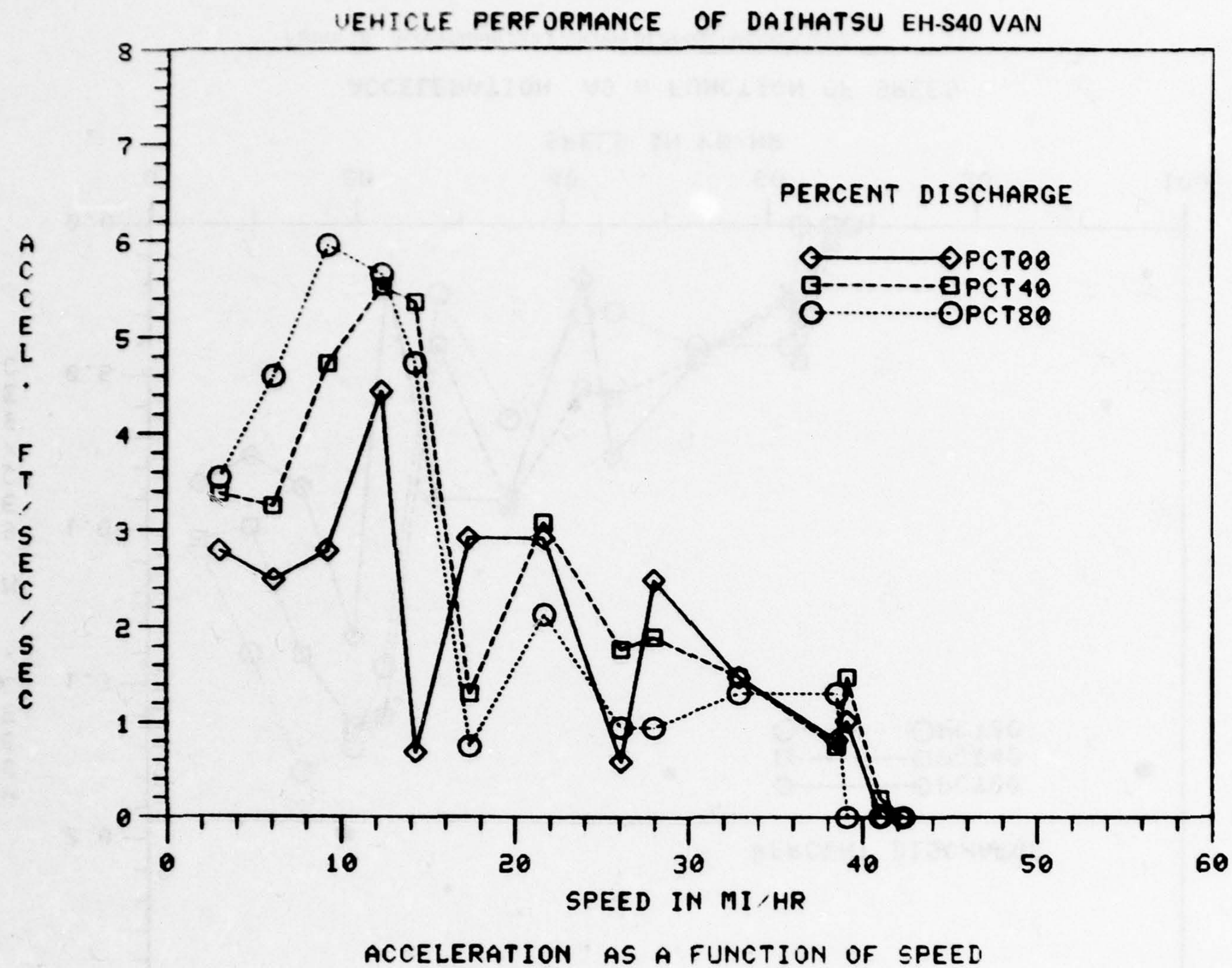

Figure 5A. Acceleration as a Function of Speed (English Units).

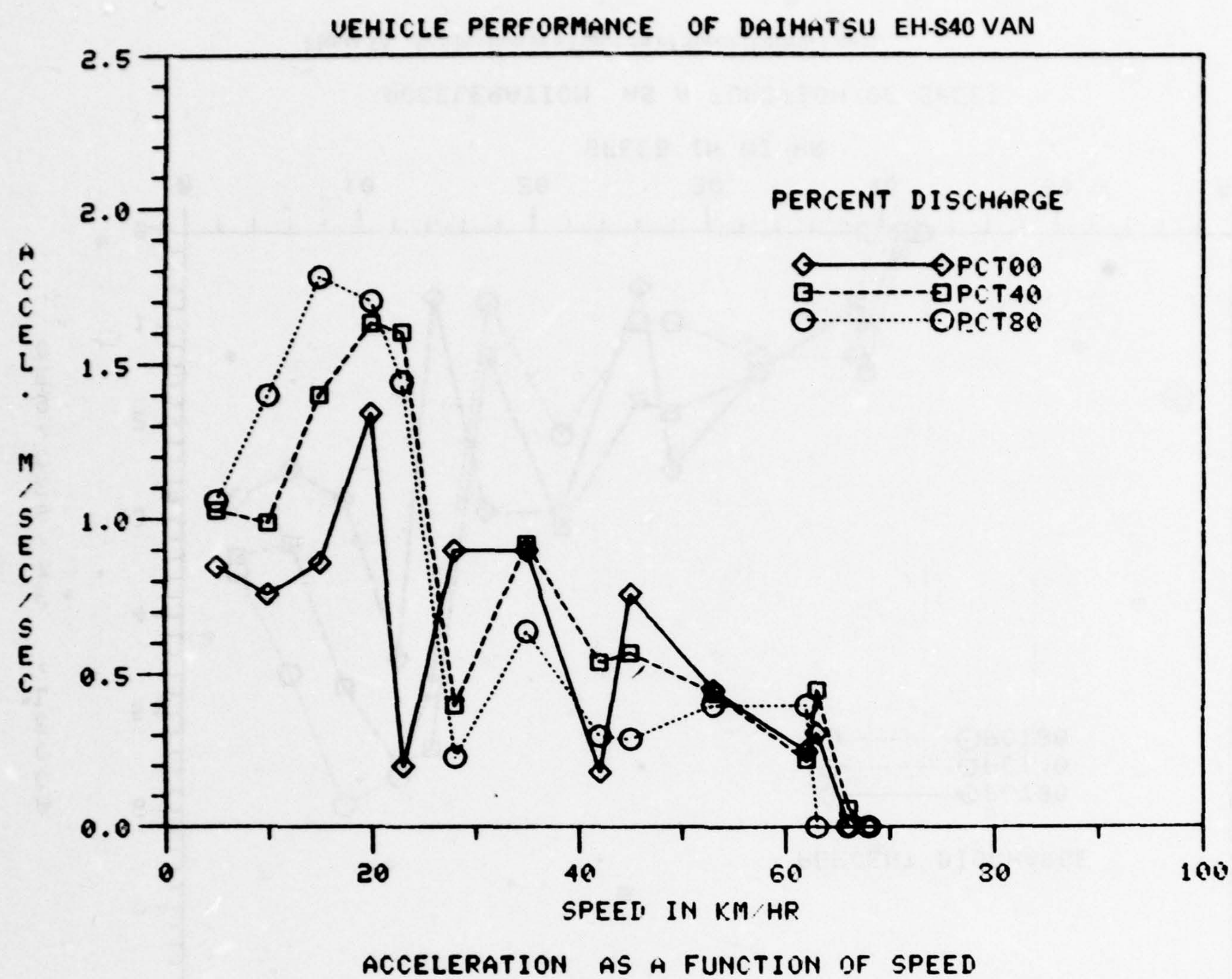

Figure 5B. Acceleration as a Function of Speed (Metric Units).

Table 5. Acceleration Test

Time (s)	Vehicle Speed km/h (mi/h) 0% Discharged		40% Discharged		80% Discharged	
1.8	4.6	2.9	1.9	1.2	1.8	1.1
3.0	7.9	4.9	6.4	4.0	5.0	3.1
4.8	12.8	8.0	13.2	8.2	14.3	8.9
6.0	17.1	10.6	20.4	12.7	21.7	13.5
7.2	22.7	14.1	26.3	16.3	26.2	16.3
10.2	25.2	15.7	32.7	20.3	32.1	19.9
12.0	31.4	19.5	38.4	23.9	36.9	22.9
13.8	37.3	32.2	42.3	26.3	40.2	25.0
16.2	42.0	26.1	45.2	28.1	42.5	26.4
19.8	46.4	28.8	52.6	32.7	44.3	27.5
22.2	50.0	31.1	55.4	34.4	46.7	29.0
25.2	55.6	34.5	60.1	37.3	52.1	32.4
28.2	59.6	37.0	63.0	39.1	55.8	34.7
32.4	62.3	38.7	64.9	40.3	58.8	36.5
36.0	64.4	40.0	66.0	41.0	60.4	37.5
41.4	64.8	40.3	66.9	41.6	61.7	38.3
45.0	65.3	40.6	67.4	41.9	62.2	38.7
48.0	65.5	40.7	67.7	42.1	62.5	38.8
54.0	65.8	40.9	68.2	42.4	63.2	39.3
60.0	66.0	41.0	67.9	42.2	63.2	39.3

Table 6. Acceleration Characteristics

Vehicle Speed		0% Discharged		40% Discharged		80% Discharged	
(km/h)	(mi/h)	(m/s^2)	(ft/s^2)	(m/s^2)	(ft/s^2)	(m/s^2)	(ft/s^2)
5	3.1	.85	2.79	1.03	3.38	1.08	3.54
10	6.2	.76	2.49	.99	3.25	1.4	4.59
15	9.3	.85	2.79	1.44	4.72	1.81	5.94
20	12.4	1.35	4.43	1.68	5.51	1.72	5.64
23	14.3	.21	.69	1.63	5.35	1.44	4.72
28	17.4	.89	2.92	.40	1.31	.23	.75
35	21.7	.89	2.92	.94	3.08	.65	2.13
42	26.1	.18	.59	.54	1.77	.29	.95
45	28.0	.76	2.49	.58	1.90	.29	.95
53	32.9	.45	1.48	.45	1.48	.40	1.31
62	38.5	.25	.82	.23	.75	.40	1.31
63	39.1	.31	1.02	.45	1.48	0	0
66	41.0	0	0	.06	.197	0	0
68	42.3	0	0	0	0	0	0

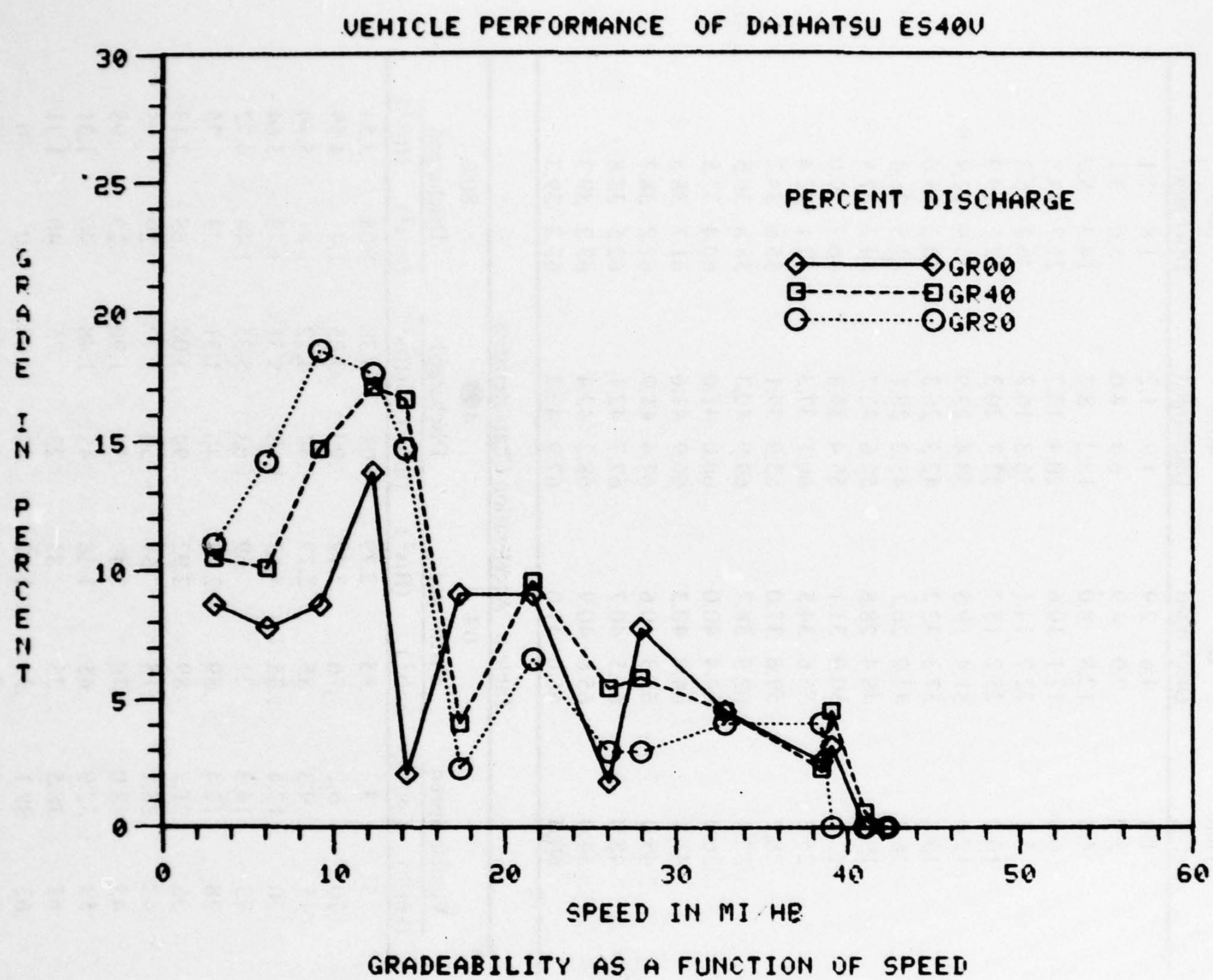

Figure 6A. Gradeability as a Function of Speed (English Units).

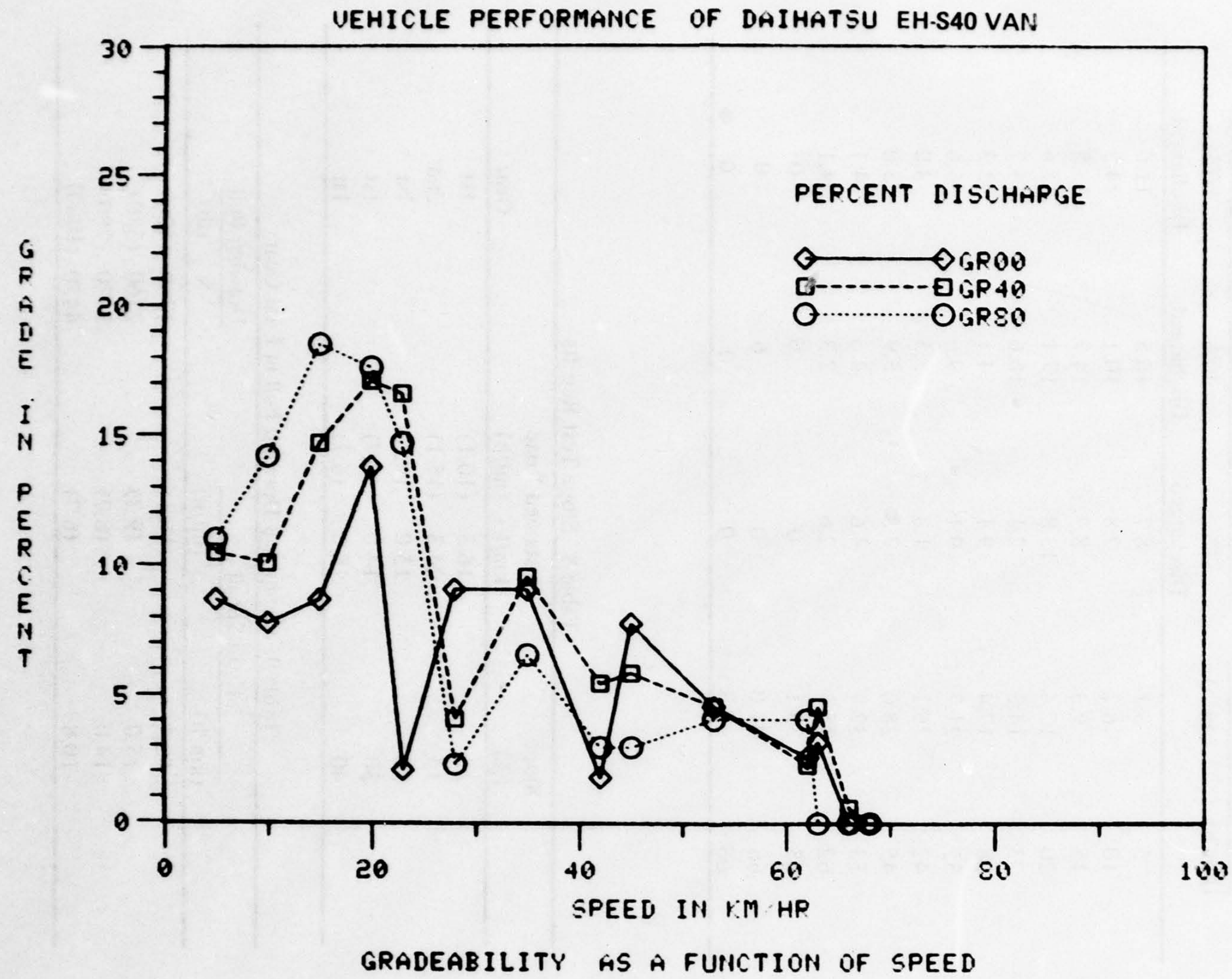

Figure 6B. Gradeability as a Function of Speed (Metric Units).

Table 7. Gradeability

Vehicle Speed (km/h)	Vehicle Speed (mi/h)	Gradeability, Percent 0% Discharged	Gradeability, Percent 40% Discharged	Gradeability, Percent 80% Discharged
5	3.1	8.7	10.5	11.0
10	6.2	7.8	10.1	14.2
15	9.3	8.7	14.7	18.5
20	12.4	13.8	17.1	17.6
23	14.3	2.1	16.6	14.7
28	17.4	9.1	4.1	2.3
35	21.7	9.1	9.6	6.6
42	26.1	1.8	5.5	3.0
45	28.0	7.8	5.9	3.0
53	32.9	4.6	4.6	4.1
62	38.5	2.6	2.3	4.1
63	39.1	0	.6	0
66	41.0	0	.6	0
68	42.3	0	0	0

Table 8. Slope Test Results

Slope (%)	Sustained Road (km/h)	Sustained Road (mi/h)	Gear
15	16.3	(10.1)	1st
15	24.3	(15.1)	2nd
20	15.0	(9.3)	1st
30	14.0	(8.7)	1st
40	10.8	(6.7)	1st

Table 9. Computed Drawbar Pull in First Gear

Road Speed (km/h)	Road Speed (mi/h)	Drawbar Pull N	Drawbar Pull (lb)
16.3	(10.1)	1780	(400)
15.0	(9.3)	2360	(530)
14.0	(8.7)	3470	(780)
10.8	(6.7)	4450	(1000)

to develop a drawbar potential of 9790 N (2200 lb) at 1.6 km/h (1 mi/h). This will require an 0.81 coefficient of traction; 0.7 to 0.75 is normal for a wheeled vehicle on a concrete surface.

In addition to the aforementioned longitudinal slope performance, the manufacturer's representative requested that repetitive 30-percent slope runs be performed to ascertain battery potential decay versus sustained road speeds. One battery of the group was selected for specific gravity determination after each test run. These tests were performed immediately after all the other longitudinal tests were completed; therefore, the battery potential had depreciated somewhat as indicated by the first specific gravity reading of 1.240; fully charged, the battery specific gravity should be within 1.270 to 1.285. Thirty-two consecutive test runs were made over the 30-percent slope, and the battery specific gravity dropped from 1.240 to 1.145, very near a discharged condition. During these runs the sustained road speed decreased from 13.8 to 11.9 km/h (8.6 to 7.4 mi/h).

Longitudinal slope performance of the van was considered satisfactory up to and including a 30-percent slope. When more than one run was attempted on a 40-percent slope, the clutch slipped.

4. **Road Energy Consumption.** Road energy is a measure of the energy consumed in overcoming the vehicle's aerodynamic and rolling resistance plus the energy consumed in the differential drive shaft and the portion of the transmission rotating when in neutral. Road energy is obtained during coast-down with the differential being driven only by the wheels.

The road energy consumed for the vehicle at various speeds and the losses in the differential were determined from coast-down tests. Road energy consumption (E_n) is calculated as megajoules per killometer from the following equation:

$$E_n = 2.78 \text{ X } 10^{-4} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \frac{MJ}{KM}$$

or in English units:

$$E_n = 9.07 \text{ X } 10^{-5} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \frac{kWh}{mi}$$

where: V = vehicle speed in kilometers per hour (km/h) or in miles per hour (mi/h).

t = time, s.

The results for the road energy determination are shown in Figures 7A, B, and C and Table 10.

Table 10. Road Energy Consumption

Vehicle Speed		Road Energy		
km/h'	(mi/h)	MJ/km	kWh/km	kWh/mi
59.7	37.1	0.45	0.125	0.2
46.3	28.8	0.38	0.106	0.17
35.4	22.0	0.32	0.09	0.14
24.0	14.9	0.27	0.08	0.12
11.3	7.0	0.22	0.06	0.09

5. Road Power Requirements. The road power is a measure of vehicle aerodynamic and rolling resistance plus the differential, drive shaft, and a portion of the transmission's power loss.

The road power "P_n" required to propel a vehicle at various speeds is also determined from the coast-down tests. The following equations are used:

$$P_n = 3.86 \text{ X } 10^{-5} W \frac{V^2_{n-1} - V^2_n}{t_n - t_{n-1}}, \text{ kW}$$

or in English units

$$P_n = 6.08 \text{ X } 10^{-5} W \frac{V^2_{n-1} - V^2_n}{t_n - t_{n-1}}, \text{ hp}$$

The results of road power calculations are shown in Figures 8A and 8B and Table 11.

6. Indicated Energy Consumption. The vehicle indicated energy consumption is defined as the energy required to recharge the battery after a test divided by the vehicle range achieved during the test, where the energy is measured as the input to the battery charger.

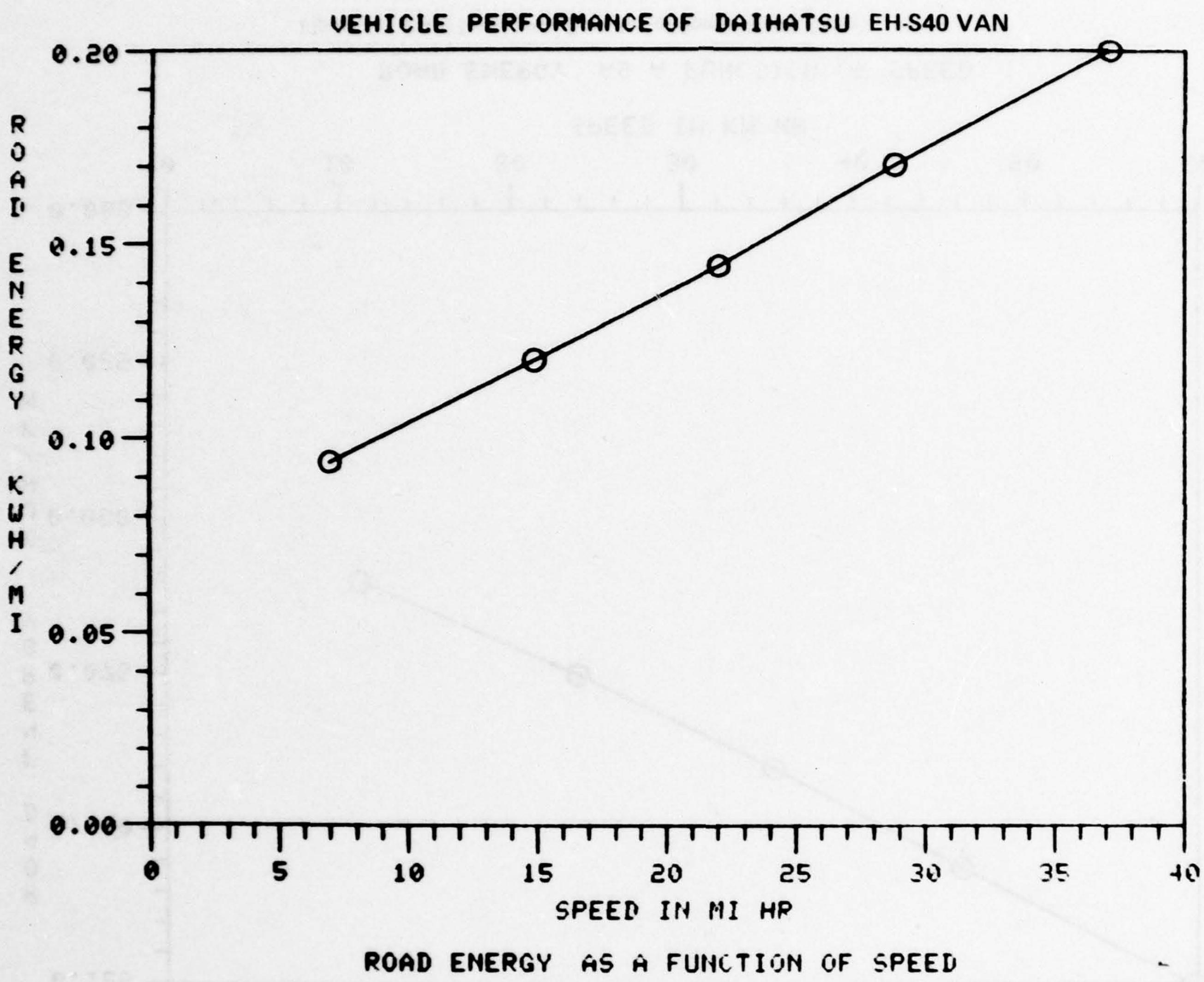

Figure 7A. Road Energy as a Function of Speed (English Units).

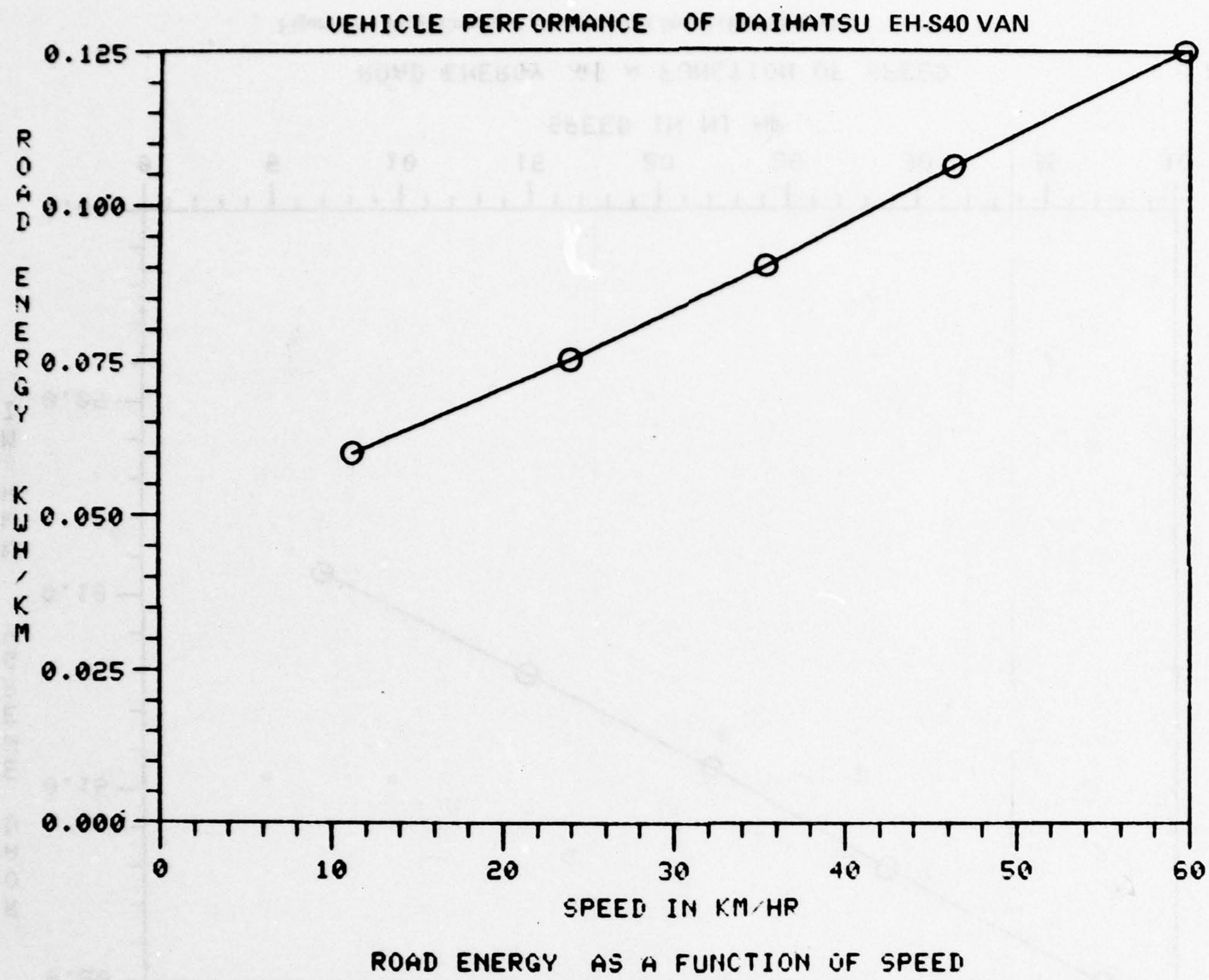

Figure 7B. Road Energy as a Function of Speed (Metric Units).

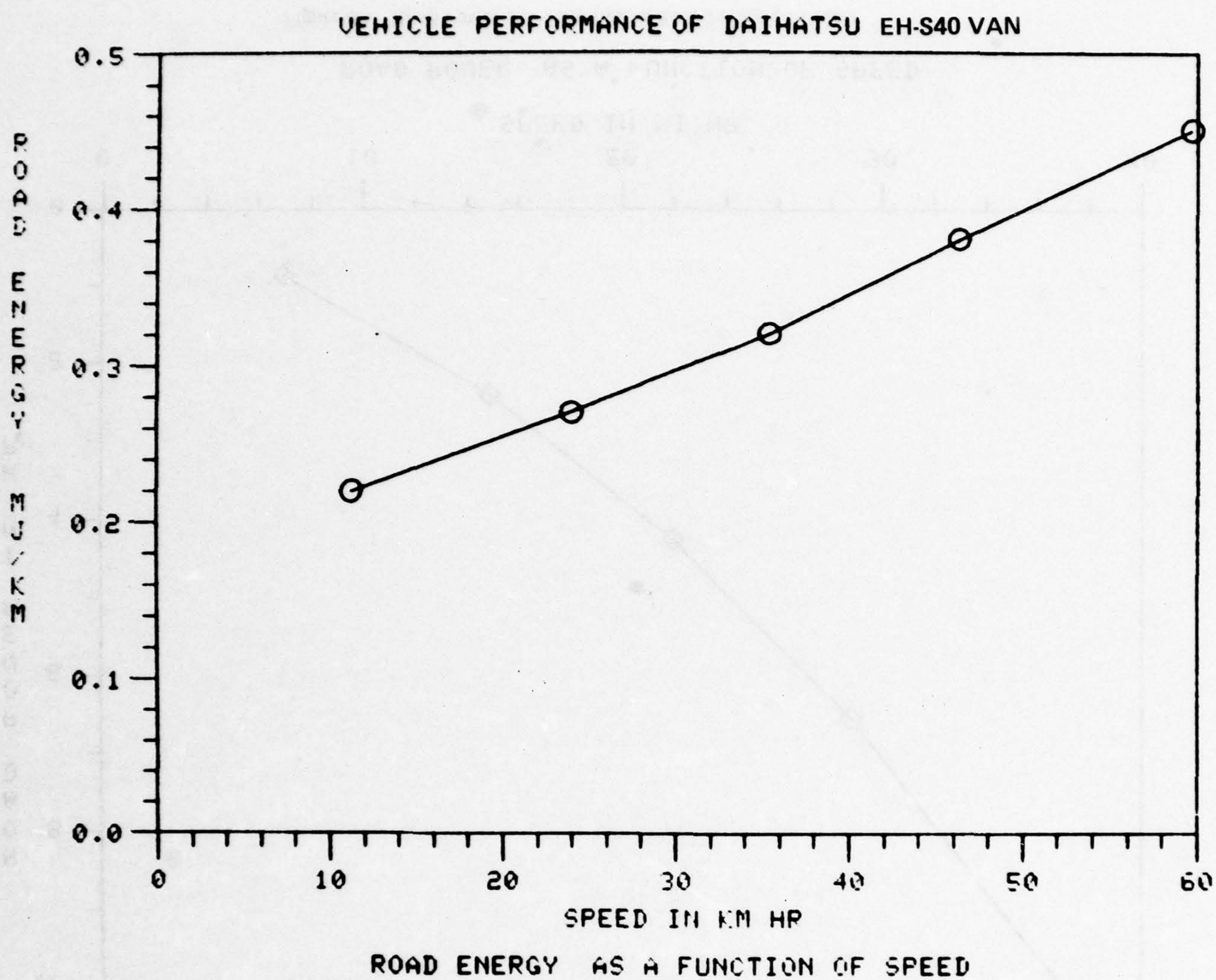

Figure 7C. Road Energy as a Function of Speed (Metric Units).

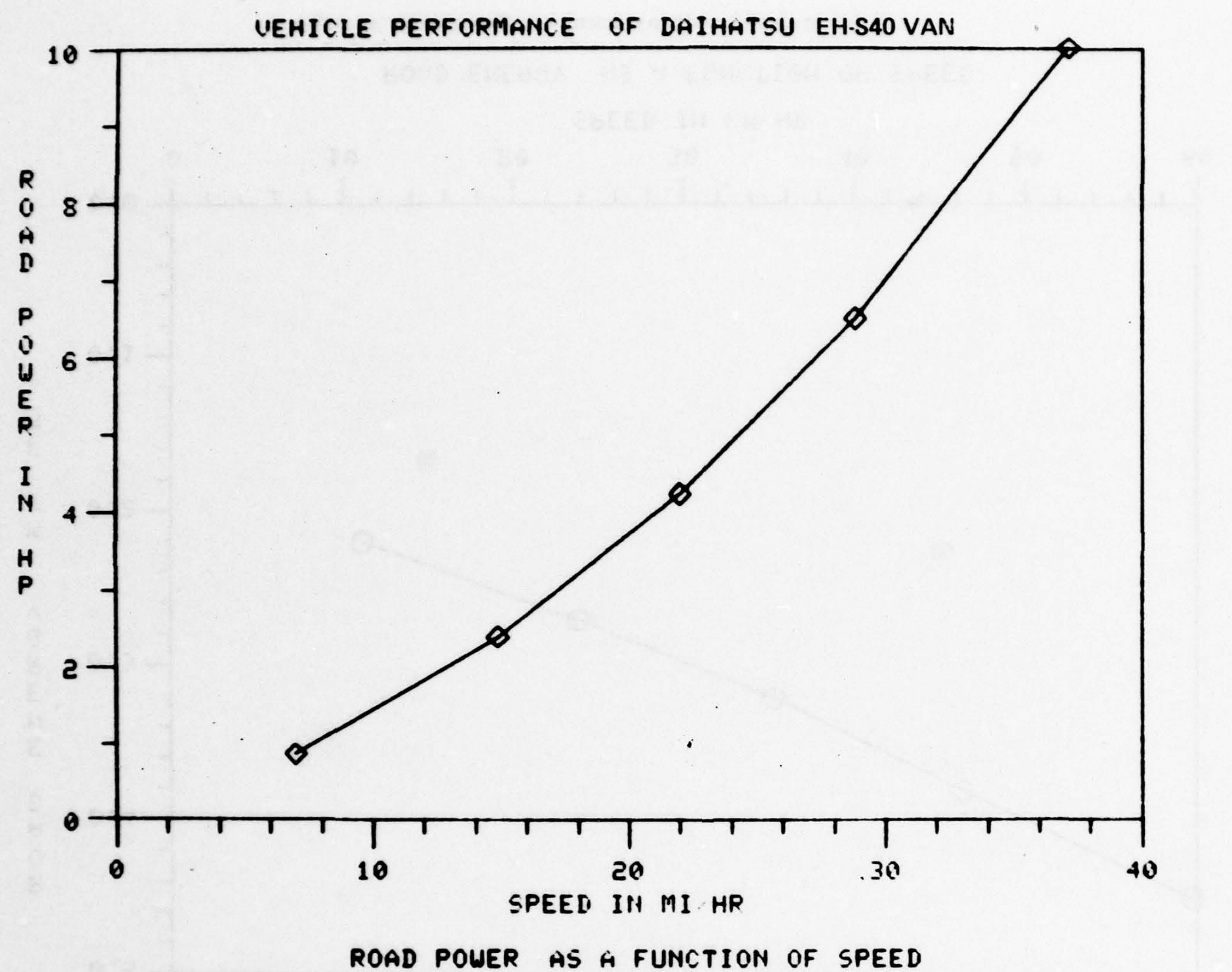

Figure 8A. Road Power as a Function of Speed (English Units).

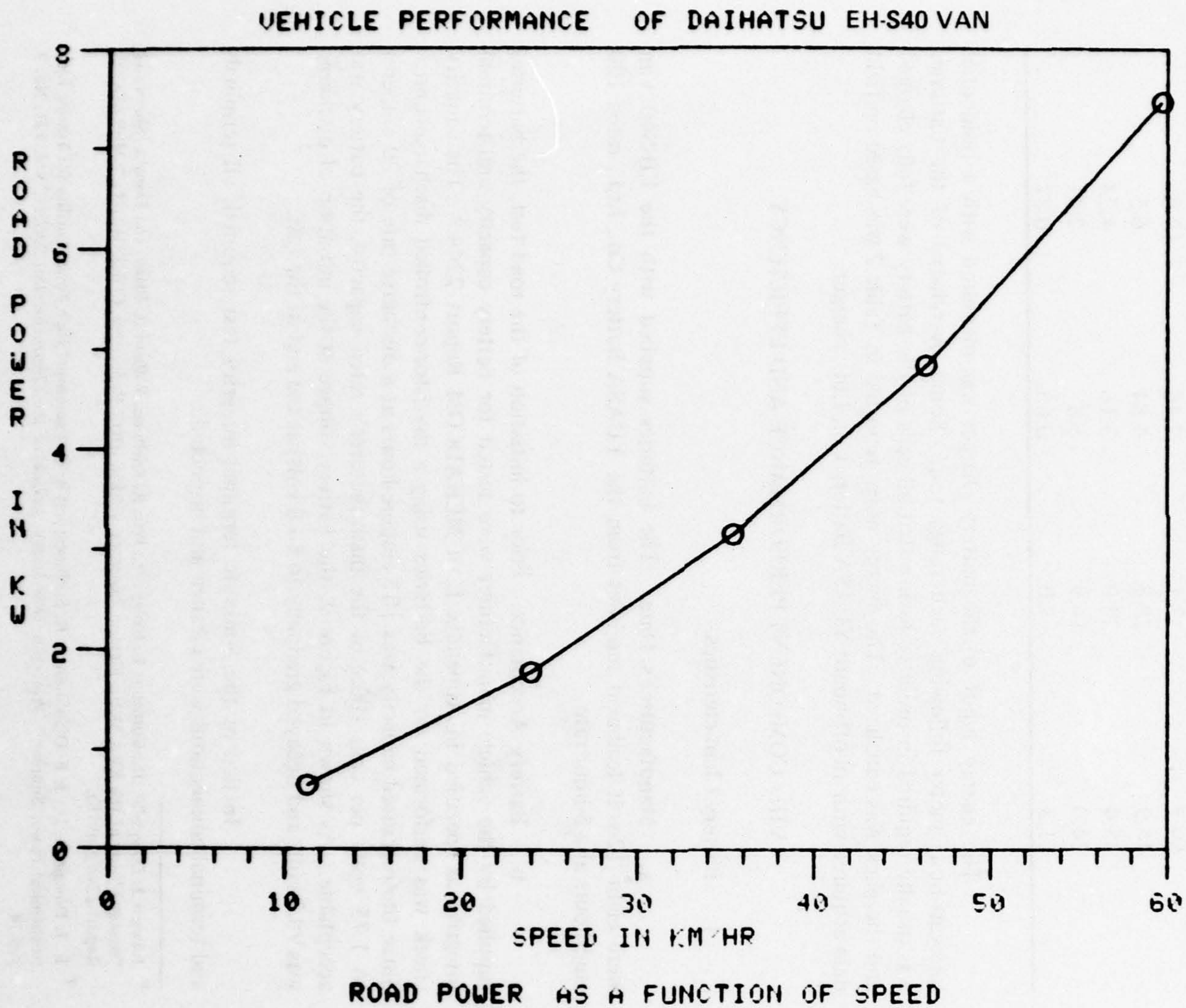

Figure 8B. Road Power as a Function of Speed (Metric Units).

Table 11. Road Power Requirements

Vehicle Speed		Road Power Required	
km/h	(mi/h)	kW	(hp)
59.7	37.1	7.46	10.0
46.3	28.8	4.84	6.5
35.4	22.0	3.16	4.24
24.0	14.9	1.8	2.41
11.3	7.0	0.66	0.87

The energy input to the battery charger was measured with a residential kilowatt-hour meter following each range test. Some overcharge of the batteries was usually required in order to assure that all cells of the battery were fully charged and the pack was equalized. The energy usage reported in Table 2 was based on field data acquired with an off-board YUASA Battery Co., Ltd., charger.

VIII. COMPONENT PERFORMANCE AND EFFICIENCY

1. Battery Characteristics.

a. Manufacturer's Data. The batteries supplied with the EH-S40 Van were eight 12-volt lead-acid modules from the YUASA Battery Co., Ltd., rated 100 amp-hours at a 5-hour rate.

b. Battery Acceptance. Prior to initiation of the road test, the batteries supplied by the vehicle manufacturer were tested for battery capacity and terminal integrity as specified in Appendix E of MERADCOM Report 2244.[6] The capacity check was performed on the batteries using a thyristor-controlled discharge unit.[7] Since the measured capacity was 101 ampere-hours at a discharge rate of 20 amperes to 1.75 volts per cell, 100% of the manufacturer's rated capacity, the battery was acceptable. As shown in Figure 9, the battery voltage at the initiation of discharge was 98.2 volts and decayed gradually to 84.0 volts at the end of the test.

In lieu of the 5-minute terminal integrity test required, all terminals and terminal connections were cleaned and inspected.

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[6] Edward J. Dowgiallo, Jr.; Cornelius E. Bailey, Jr.; Ivan R. Snellings; William H. Blake; and Donald Sherwood; "Baseline Tests of the EVA Metro Electric Passenger Vehicle (DOE Report No. CONS/0421-1)." MERADCOM Report 2244 (Jul 78).

[7] E. J. Dowgiallo, Jr.; J. B. O'Sullivan; I. R. Snellings; and R. B. Anderson; "High Power Facility for Testing Electrochemical Power Sources." Princeton, New Jersey; *Journal of the Electrochemical Society*, Vol. 121, No. 9, Sep 74.

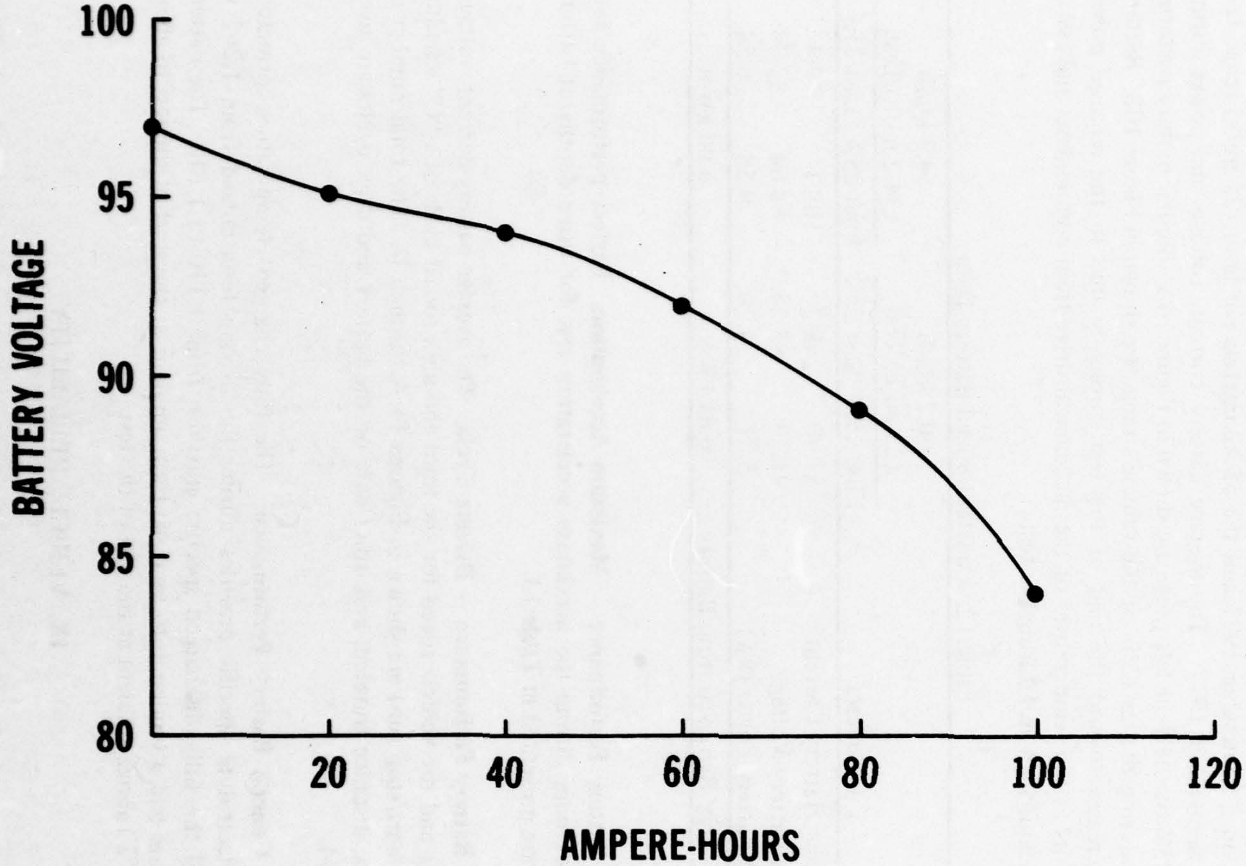

Figure 9. Battery Voltage as a Function of Capacity Removed.

2. **Constant Vehicle Speed Battery Performance.** During the road tests, battery current and motor voltage were monitored constantly. Figures 10A and 10B and Table 12 present the battery characteristics during the 40 kilometers per hour (25 mi/h) range test on 2 September 1977 and the 55 kilometers per hour (35 mi/h) range test run on 1 September 1977. The average battery current, voltage, and power during the first 25% of the vehicle's range are shown in Figure 10A. Similar battery performance data during the last 25% of the vehicle's range are shown in Figure 10B. Battery power decreases toward the end of the test, probably due to the reduced power requirements as the temperature of the mechanical drive train components and associated lubricants increases during the test.

Table 12. Constant Speed Battery Data

Parameter	40.2 km/h (25 mi/h) Test		54.7 km/h (34.2 mi/h) Test	
	First 25%	Last 25%	First 25%	Last 25%
I_B Average Battery Current	57.90	49.2	108.1	79.4
Average Battery Voltage	91.79	85.28	88.64	82.34
Average Battery Power (kw)	5.31	4.20	9.58	6.54
Total Energy Removed from Battery	6.81 kW-h		6.00 kW-h	

3. **Battery Performance – Maximum Acceleration.** Battery performance data at selected times during the maximum acceleration test for three depths of battery discharge are presented in Table 13.

4. **Battery Performance – Driving Cycle.** The average battery current, voltage, and power and the vehicle speed for the third and next-to-last cycle of a "C" schedule (30-mi/h start/stop run) are shown in Figures 11 A through D. The total number of start/stops, distance traveled, and other data on the battery and drive cycles are given in Table 14.

5. **General Battery Performance.** The fully charged (temperature-corrected) battery electrolyte specific gravities during the driving tests ranged from 1.262 to 1.291 and the fully discharged specific gravities, from 1.110 to 1.140. The battery temperature had a tendency to increase from ambient at the start of the test to about 10°C (17°F) above ambient at the end of the test.

IX. VEHICLE RELIABILITY

No major problems were encountered. Tests were abbreviated and some eliminated because of the limited time that the vehicle was available. All braking tests were deleted at the request of Daihatsu.

DAIHATSU **EH-S40 VAN**

CONSTANT SPEED BATTERY PERFORMANCE

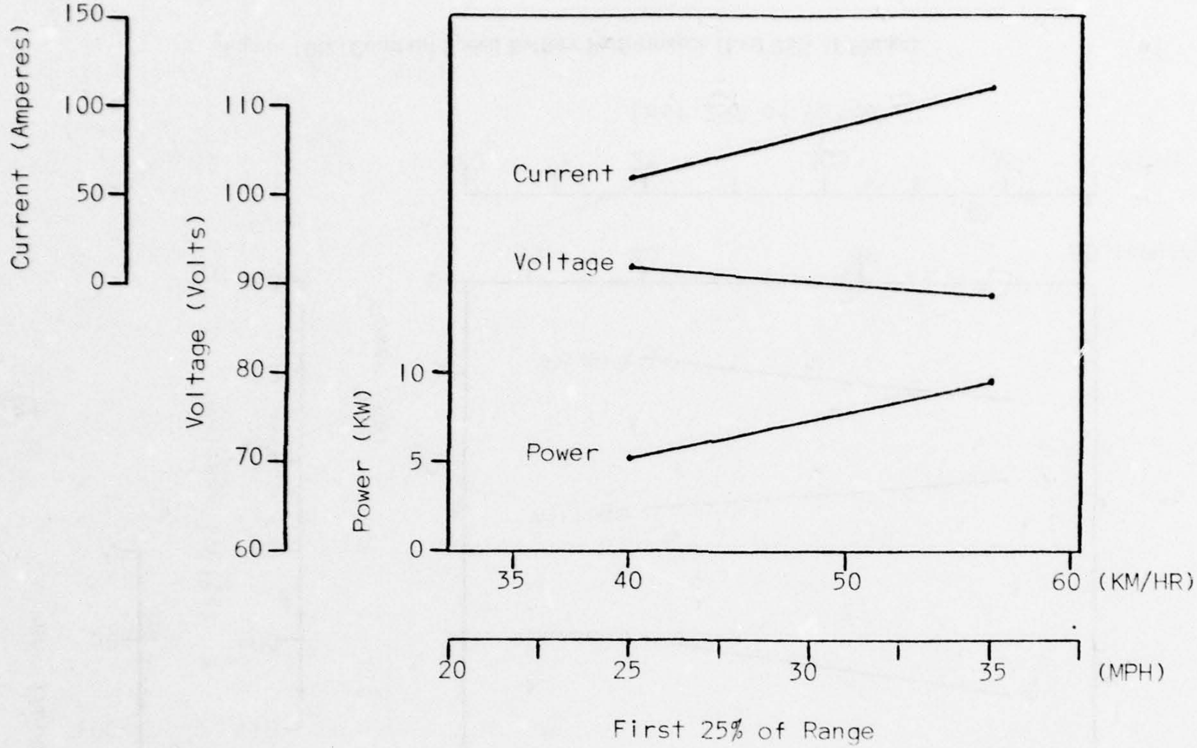

Figure 10A. Constant Speed Battery Performance (First 25% of Range).

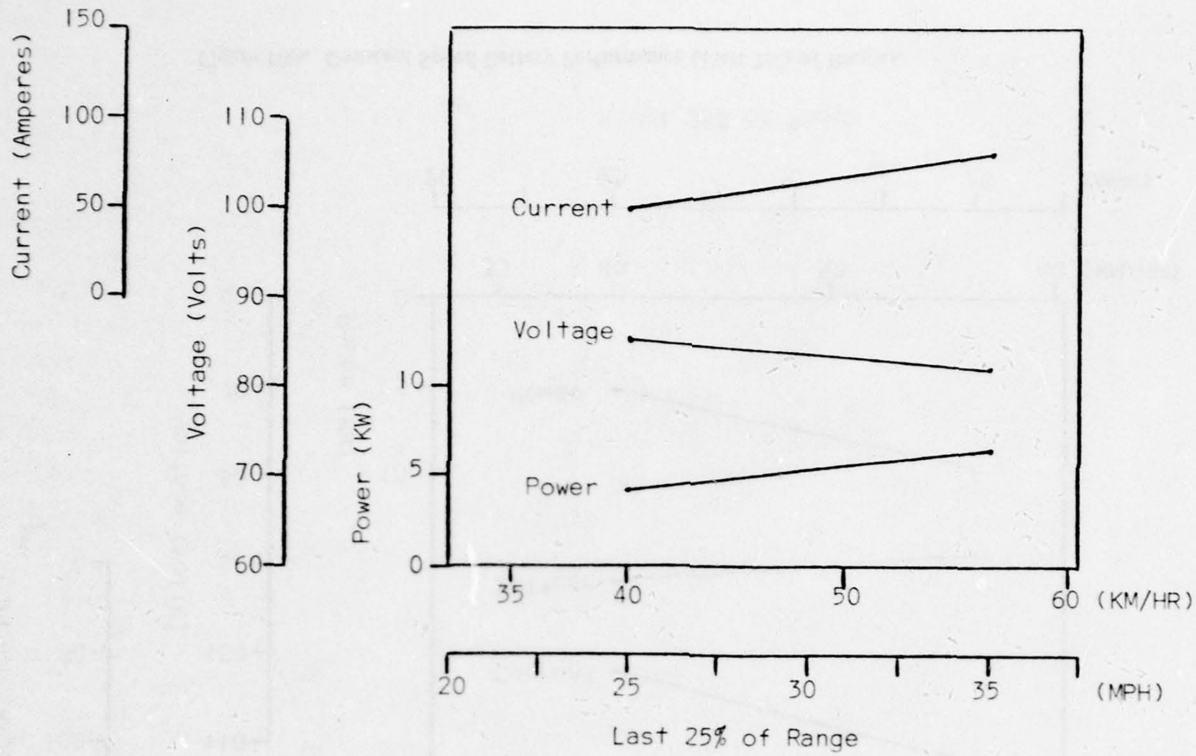

Figure 10B. Constant Speed Battery Performance (Last 25% of Range).

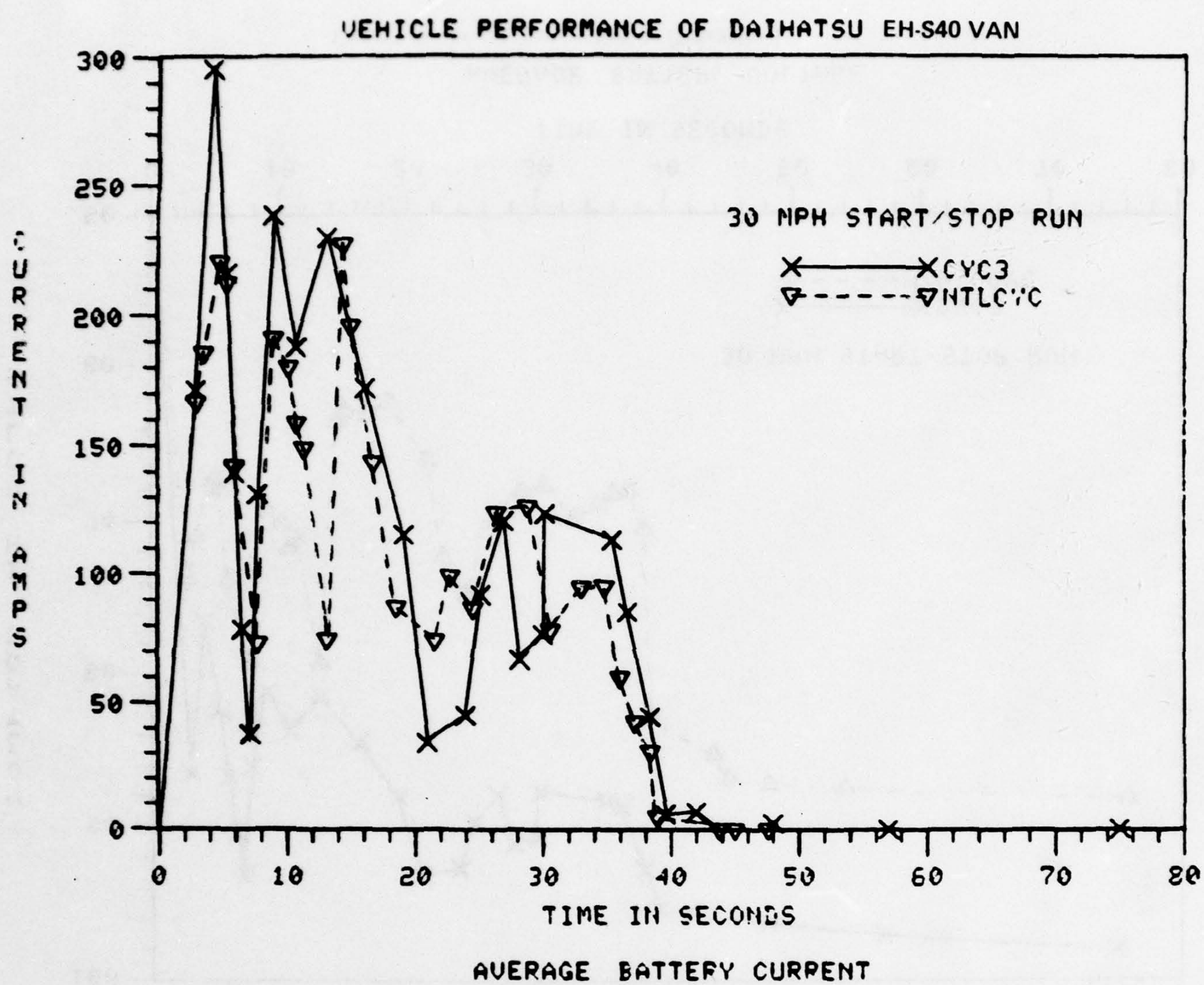

Figure 11A. Average Battery Current (Schedule C).

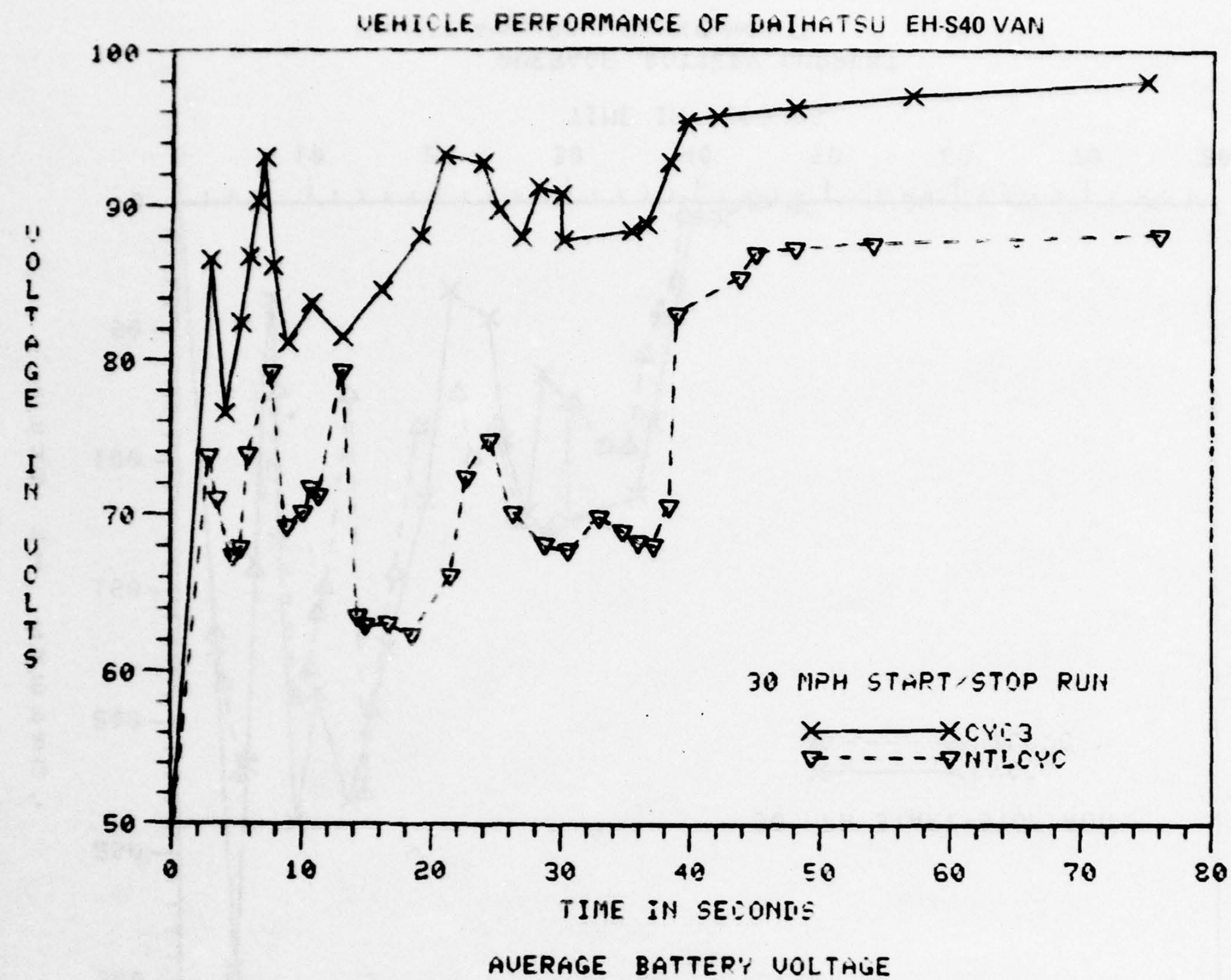

Figure 11B. Average Battery Voltage (Schedule C).

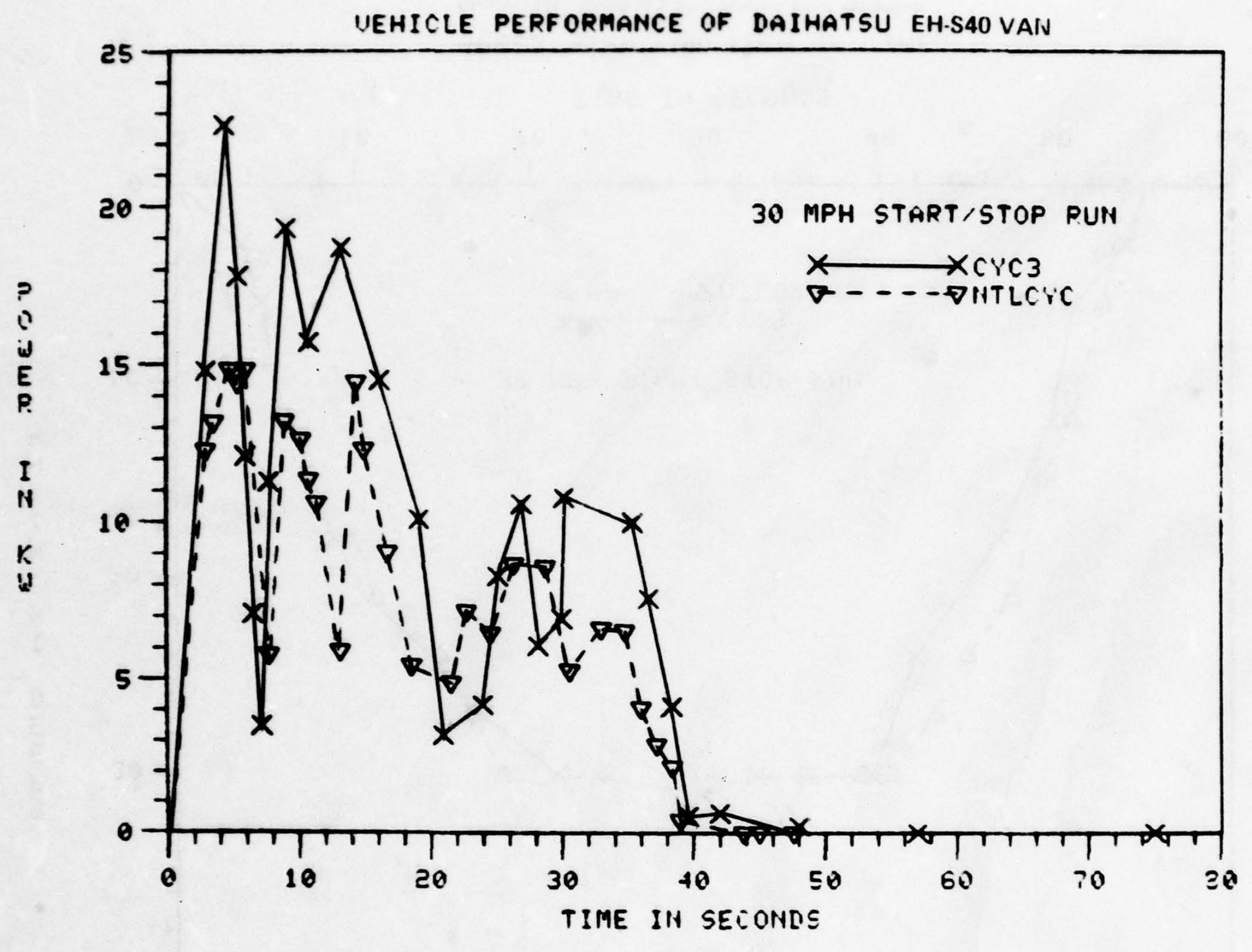

Figure 11C. Average Battery Power (Schedule C).

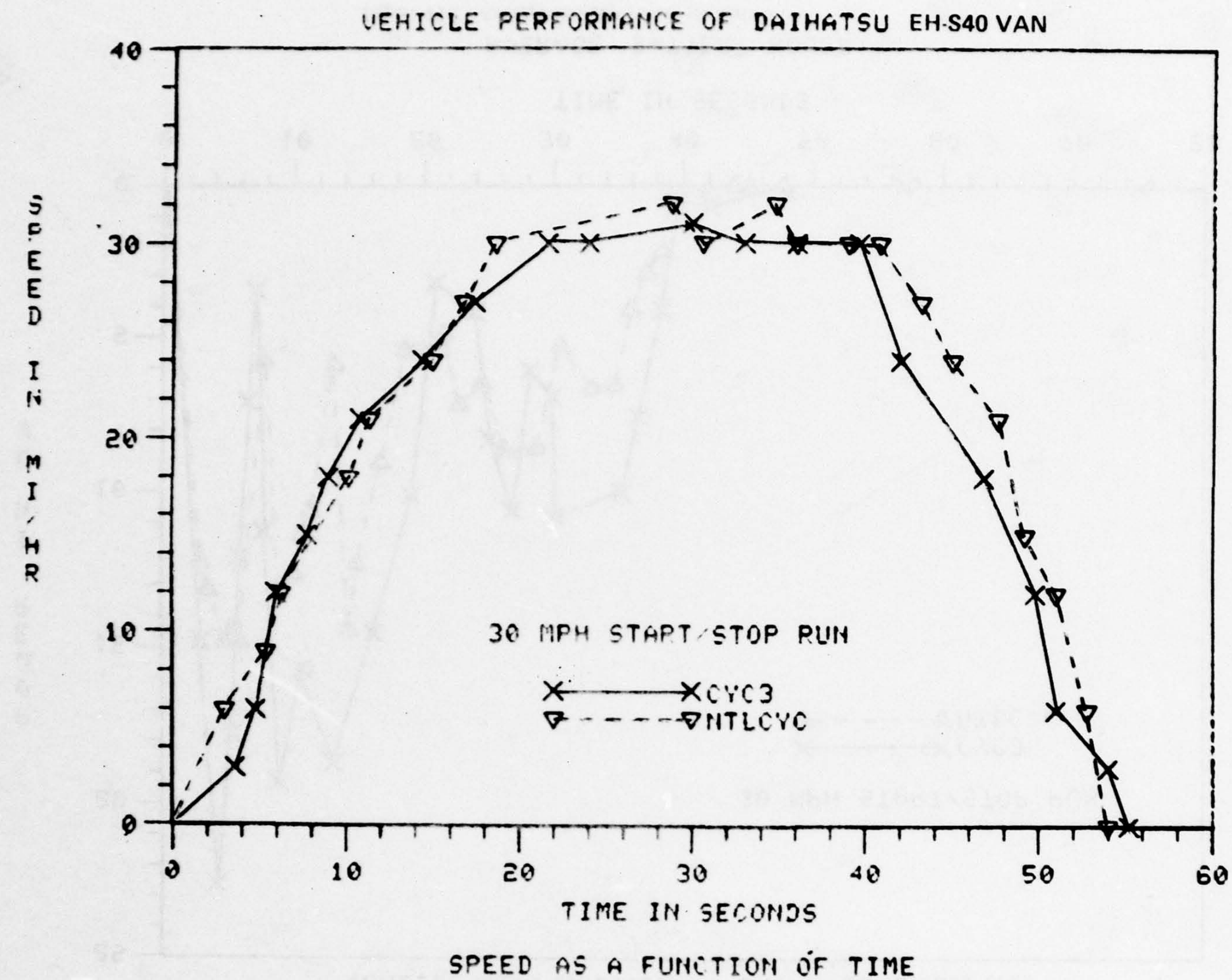

Figure 11D. Speed as a Function of Time (Schedule C).

Table 13. Maximum Acceleration Battery Performance

Time (s)	Speed (mi/h)	Speed (km/h)	Current (A)	Voltage (V)	Power (kW)	Discharge (%)
5	8.3	13.3	120	87.2	10.5	0
10	15.3	24.6	205	82.3	16.9	0
20	29.1	46.8	220	82.0	18.0	0
40	40.1	64.5	132	87.2	11.5	0
60	41.0	66.0	122	88.2	10.8	0
5	8.9	14.4	250	78.6	19.7	40
10	19.9	31.9	219	80.0	18.5	40
20	32.8	52.8	213	80.3	17.1	40
40	41.6	66.9	125	85.8	10.7	40
60	42.2	67.9	118	86.0	10.1	40
5	9.7	15.6	228	73.1	16.7	80
10	19.5	31.3	213	74.0	15.8	80
20	27.5	44.3	71	84.8	6.0	80
40	38.0	61.1	118	79.5	9.4	80
60	39.4	63.3	107	80.9	8.7	80

Table 14. Driving Cycle Performance

Parameter	Schedule B	Schedule C
Total start/stop cycles	106	58
Distance traveled during test, km (mi)	37.8 (23.5)	32.8 (20.4)
Test period, hours	2.18	1.28
Kilowatt-hours used during test	6.93	5.44
Average watt-hours used per cycle	65.6	93.8
Amp-hours used during test	95.4	70.5
Average amp-hours used per cycle	0.90	1.22
Average cycle duration	.0206 h (74 s)	.0221 h (79 s)
Average time battery is loaded per cycle	.0113 h (40.5 s)	.0111 h (40 s)
Percent of power used for accelerating to cruise speed	69%	70%

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1. Vehicle Manufacturer: Name and Address

   Daihatsu Motor Company, Ltd.
   1-1, Daihatsu-Cho, Ikeda-City
   Osaka, Japan

2. Vehicle Description

   Name: Hi Jet Van EV   Model: S40-817192
   Availability: Price:

3. Vehicle Weight

   Curb Wt: 924 kg (2035 lb)   Passengers Wt: 8.44 kg (186 lb)
   Driver Wt: 8.98 kg (196 lb)   Payload Wt: 142.58 kg (315 lb)
   Gross Weight: 1240 kg (2734 lb)

4. Vehicle Size

   Wheelbase: 1680 mm   Length: 3090 mm   Width: 1295 mm
   Headroom: 880 mm   Legroom: 430 mm

5. Auxiliaries & Options

   No. Lights: 10
   a. Head Lamps
   b. Front-Turn Signal Lamps
   c. Side-Turn Signal Lamps
   d. Rear Combination Lamps
   e. License Plate Lamp
   f. Back-up Lamp

   Windshield Wipers: Yes   Windshield Washers: Yes
   Defroster: Yes   Heater: Yes
   Radio: No   Fuel Gage: Yes   Ampmeter: No
   Tachometer: No   Speedometer: Yes
   Odometer: Yes   No. Mirrors: 3

Power Steering: No   Power Brakes: No
Transmission Type: 4-Speed Manual Transmission

6. Propulsion Batteries

Type: Lead-Acid   Manufacturer: YUASA Battery Co., Ltd.
No. of Modules: 8-12 v
No. Cells: 48-2 v   Battery Voltage: 96 v
Ah Capacity: 100 Ah   Battery Size: 407L 173W 252H mm
Battery Wt: 256 kg (564.48 lb)   Battery Age: January 1977
Battery Rate: 20 Amperes 5 hours

7. Auxiliary Battery

Type: Lead-Acid   Manufacturer: YUASA Battery Co., Ltd.
No. Cells: 6-2 v   Battery Voltage: 12 v
Ah Capacity: 26 Ah   Battery Size: 176L 125.5W 186H mm
Battery Rate: 10-hour rate   Battery Wt: 8 kg (17.64 lb)

8. Controller

Type: Transistor Hybrid   Manufacturer: Daihatsu Motor Co. Ltd.
Voltage Rating: 96 v   Current Rating: 200 A
Size: (separate in 3 pieces)   Weight: 40 kg (88 lb)

9. Propulsion Motor

Type: d.c. Shunt   Manufacturer: Tokyo Shibaura Electric Co., Ltd.
Insulation Class: F   Voltage Rating: 90 v
Current Rating: 180 A   HP Rating: 18.8 hp (14 kw)
Max. 5 Min. Rating: 24.1 hp (18 kw)   Size: 230 mm 390 mm
Weight: 55 kg (121.3 lb)   Rated Speed: 5600 r/min
Max. Speed: 8000 r/min

10. Body

Type: Cab-Steel   Manufacturer: Daihatsu Motor Co., Ltd.
No. Doors: 5   Type: Front: Hinged; Side: Sliding; Rear: Hatch Back
No. Windows: 4   Type: Front: Regulator; Rear: Sliding
No. Seats: 2+(2)   Type: Bench
Cargo Volume: 1.16 m^3 Cargo Dimensions: 975L 1120W 1060 H mm

11. Chassis

Type Frame: Ladder Manufacturer: Daihatsu Motor Co., Ltd.
Type Material: Steel
Type Springs: Front: Coil; Rear: Leaf Type Shocks: Telescopic Type
Axle Type Front: Wishbone Axle Type Rear: Rigid Axle
Axle Manufacturer: Daihatsu Motor Co., Ltd.
Drive Line Ratio: 1st: 24.61 to 1; 2nd: 14.53 to 1; 3rd: 9.478 to 1; Top: 6.478 to 1
Type Brakes Front: Drum (2 leading)
Type Brakes Rear: Drum (Leading and Trailing)
Regenerative Brakes: No
Tire Type: Bias Manufacturer: Toyo, Bridgestone, Yokohama, or Dunlop
Size: 5.00-10-4 PRULT Pressure: Front: 2.4 kg/cm^2; Rear: 2.4 kg/cm^2
Rolling Radius: 0.244 m

12. Battery Charger

Type: Const. Voltage; Const. Current Manufacturer: YUASA Battery Co., Ltd.
On or Off Board: Off-Board Input Voltage: 220 v, 3-phase
Peak Current: IN: 5.53A (a.c.); OUT: 12.6A (d.c.) Recharger Timer: 12 hr
Size: 800H 500L 500W mm Weight: 128 kg (282 lb)
Automatic Turn Off: Yes

APPENDIX B

DESCRIPTION OF VEHICLE TEST TRACK

The test site used to conduct the tests described in this report is located at Aberdeen, Maryland. The track is owned and operated by the US Army. Three test sites were used: the standard gradeability slopes, the dynamometer course, and the 1-mile loop.

1. **Gradeability Slopes.** Gradeability of vehicles is a basic characteristic usually given in design specifications of military vehicles. The Munson gradeability slopes (Figures B1 and B2) cover a range of 5 to 60 percent. They are used to determine optimum drive ratios and maximum attainable speeds on each slope, as well as brake-holding ability and adequacy of angles of approach and departure. With the test vehicle in both ascending and descending attitudes, functions such as lubrication, fuel flow, and carburetion are investigated. The effect of unbalance on turret traversing efforts and functioning of turret drive systems may also be studied on the slopes. The 5, 10, 15, and 20 percent slopes, approximately 14 feet wide, are paved with asphalt; the 30, 40, 45, 50, and 60 percent slopes, with concrete.

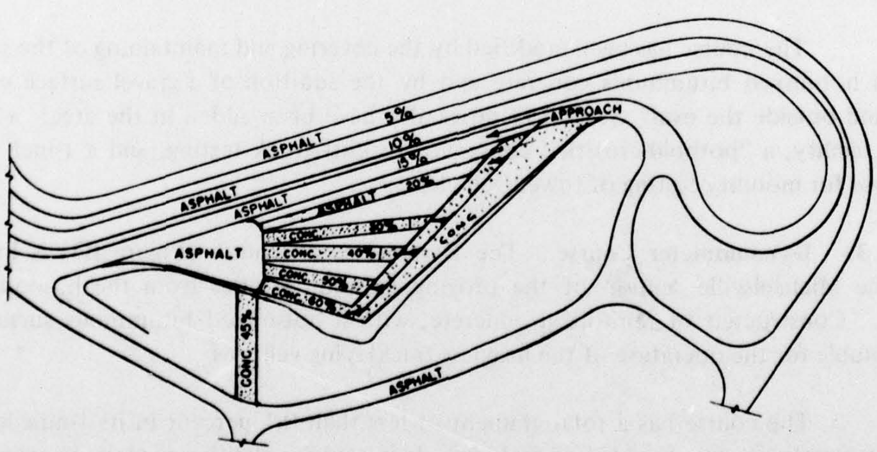

Figure B1. Plan View of Slopes.

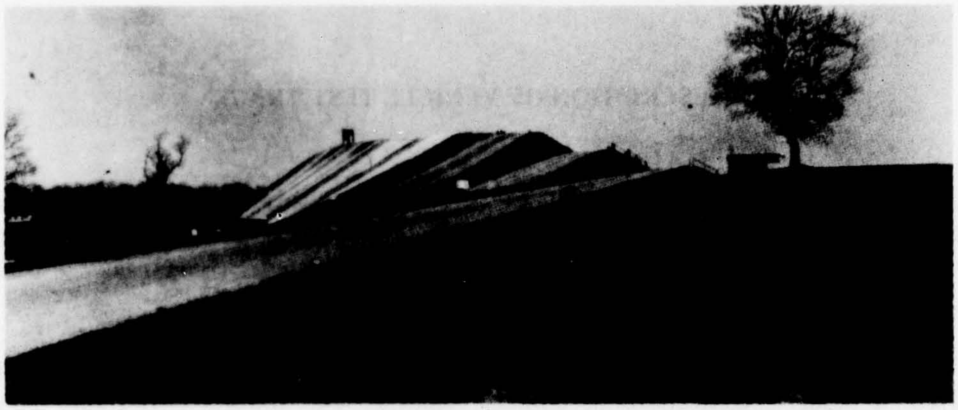

Figure B2. Eight of the Standard Gradeability Slopes.

2. **Mile Loop.** The Mile Loop (Figure B3) was originally constructed in 1933 as a level concrete course of oval shape for continuous high-speed operating tests of vehicles. Near the headquarters area of the post, the course consists essentially of two straight sections, each ¼-mile long, joined at each end by quarter-mile sections of regular curvature to form an oval of 1 mile total circumference.

The course has been modified by the covering and maintaining of the surface with hot-mixed bituminous concrete and by the addition of a gravel surface parallel to and outside the oval. Several facilities also have been added in the area: a winch test facility, a "pothold-crosstie" course for forklift truck testing, and a 1-inch bump course for mobility testing of towed vehicles.

3. **Dynamometer Course.** The Dynamometer Course (Figure B4) is located in the Michaelsville section of the proving ground, 4 miles from the headquarters area. Constructed of reinforced concrete, with a hot-mixed bituminous surface, it is suitable for the operation of the heaviest tracklaying vehicles.

The course has a total gradient of less than 0.1 percent in its 1-mile length, and turnarounds are provided at each end. It is used for closely controlled engineering tests such as drawbar-pull and tractive-resistance measurements, acceleration and braking tests, and fuel consumption measurements.

Figure B3. Aerial View of Mile Loop.

Figure B4. Dynamometer Course.

APPENDIX C

VEHICLE PREPARATION AND TEST PROCEDURE

When the vehicle was first received at MERADCOM, a number of checks were made to assure that it was ready for performance tests. These checks were recorded on a vehicle-preparation check sheet. The vehicle was examined for physical damage upon arrival. Before operating the vehicle, a complete visual check was made of the entire vehicle. The battery was charged and specific gravities taken to determine if the batteries were equalized. If not, an equalizing charge was applied to the batteries. The integrity of the internal interconnections and the battery terminals was checked by drawing 300 amps or the vehicle manufacturer's maximum allowed current from the battery for 5 minutes, if the battery terminals or interconnections temperature rose more than 60°C above ambient, the test was terminated and the terminals cleaned or the battery replaced. The batteries were recharged and a battery capacity check was made. This test was made in accordance with the battery manufacturer's recommendations. To pass this test, the capacity had to be within 20% of manufacturer's published capacity at the published rate.

When a vehicle arrived at the test site (APG), a number of checks were performed to assure that it was ready for performance testing. The wheel alignment was checked, compared, and corrected to the manufacturer's recommended alignment values. The vehicle was weighed and compared with the manufacturer's specified curb weight. The gross vehicle weight was determined by manufacturer's rated pay load.

TEST PROCEDURE

Each day data were entered on the vehicle data sheet. These data included:

1. Average specific gravity before and after test.
2. Tire pressures.
3. Fifth-wheel tire pressures.
4. Weather information.
5. Battery temperatures.
6. Test start time.
7. Test termination time.
8. Amp-hours out of the battery.
9. Fifth-wheel distance count.

10. Odometer reading before and after each test.
11. A.C. kw used for recharge.
12. D.C. amp-hours into battery on recharge.

To prepare for a test, the specific gravities were measured and recorded. The tire pressures were measured. The instrumentation was connected, and power from the instrumentation battery was applied. All instruments were turned on and warmed up, and all data channels were calibrated. The vehicle was towed to the starting point on the track. Weather data was recorded; odometer reading was taken. The test was started and carried out in accordance with the DOE test and evaluation procedure. When the test was terminated, the test team made all the proper checks and recorded all data on the data test sheet for the day's test. After all checks were made, the vehicle was towed back to the charge station and placed on charge for the next day's test.

WEATHER DATA

Measurements of wind velocity and direction and ambient temperatures were taken at the beginning and at the end of each day's testing. The APG Airport weather station was used for all weather data.

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